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STUDIES OF GRAZING OF CROP FORAGES BY SHEEP

III. INTAKE, MAINTENANCE, AND WEIGHT-GAIN REQUIREMENTS OF WETHERS GRAZING RAPE

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(*Received for publication, 26 February 1959*)

Summary

Forty-eight determinations of intake, weight and weight gain were made on sixteen young wethers free-grazing three blocks of rape in turn.

The intake of units of starch equivalents was 8% higher than that calculated from Wood and Woodman (1930) feeding tables, a difference which was significant at the 2% probability level.

A multiple-regression equation in the form of a functional relationship, which showed that maintenance requirements of the wethers were 20% higher and weight gain needs 30% lower than standard values, was derived. Both differences from standard values were very highly significant.

A second multiple-regression equation in which a constant term was included gave a more accurate prediction of intake of individual wethers than either standard values or the first equation.

Significant correlation coefficients were found between intake and weight gain, intake and weight, and weight gain and weight.

Rate of weight gain increased as grazing progressed, there being a linear increase in intake in successive blocks. This was significant at the 1% level of probability, as also were the large and consistent differences between sheep in the level of intake.

INTRODUCTION

Crop forages are grown to feed animals kept for the purpose of providing various animal products. A corollary is that evaluation of forage species or varieties should be based on the level of animal production obtainable from them. The same criterion must naturally be applied to crop and animal management practices, and to farm systems.

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The need for critical evaluation of a forage by its capacity for animal production is widely accepted by agronomists, but because of experimental difficulties this need is not often satisfied. There are many deterrents to the use of livestock in evaluating forage crops, not least of which are the subjective decisions on stock management which must be made, but which, as shown by McMeekan (1956) may bias results. To some extent this difficulty may be overcome by measuring intake, which has the additional advantage of being expressed in terms significant for plants as well as animals. Intake is a more significant measure of capacity for animal production than any other measure of crop yield, as less food is eaten than is offered for consumption and the composition of the food eaten is partly influenced by the animal (Greenall 1958a). The reports of Woodman *et al.* (1937) and Brisson *et al.* (1954) make it plain that accurate techniques, such as the consumption/excretion ratio method of Garrigus (1935), are laborious and time consuming. It seems equally apparent from the reports of Reid and Kennedy (1956), Lancaster (1954), and Raymond *et al.* (1956) that the less arduous methods now under development, though very promising, have not yet reached a high degree of precision. The use of feeding tables in reverse has probably been the method most frequently employed, but has several disadvantages. In particular, it is difficult to obtain valid and precise measures of weight gain during short feeding periods (Brown 1954), and the variation between different batches of the same forage species, or between animals, is ignored, whereas the weight of evidence points to substantial variation (Forbes 1936, Woodman *et al.* (1937), Blaxter and Graham 1955). Furthermore, the application to free-grazing animals of maintenance requirements determined with sheep confined in respiration experiments is open to criticism. As late as 1926, values for maintenance requirements of sheep calculated independently by Armsby (1917) and by Woodman *et al.* (1926) differed by as much as 70%. However, the classic work of Wood and Capstick (1926) resulted, from the statistical analyses of a large number of feeding experiments with sheep, in the calculation of maintenance requirements which have been widely used, with only minor modifications, since that date. Wood and Capstick recognised, and it was later pointed out by Woodman *et al.* (1926) that maintenance values were about 17% above values of true basal metabolism, by an estimated 2% for food stimulus and 15% for energy of standing, and that additional energy would be required for free-grazing sheep. The amount of additional energy for locomotion of free-grazing ruminants must doubtless be dependent on the yield of acceptable forage per unit area (Hancock 1954; England 1954), the size of the enclosed area (Shepperd 1921), its shape, slope, and physical condition, and on stocking intensities, and, unlike basal metabolism, is probably more closely related to animal weight than to surface area. As has been emphasised by McMeekan (1942), critical work on the nutriton of animals requires individual feeding techniques, which, for a better understanding of the maintenance and weight-gain requirements of sheep grazing rape *in situ,* necessitate measuring the intake, weight, and weight gain of each sheep.

The questions which this experiment was designed to answer were:

(a) Does the use of standard feeding tables in reverse provide an accurate measure of the intake of wethers grazing rape?

(b) If not, what values for maintenance and weight gain are more appropriate?

(c) What effects do level of intake and efficiency of feed utilisation have on animal productivity?

METHODS

A standard digestibility experiment was fully described in the first paper of this series (Greenall 1958a).

The apparent digestibility coefficients of dry matter, organic matter, and the food constituents of rape of Blocks II, III, and IV, as well as consumption/excretion ratios, were determined. The total faeces excreted by each of the sixteen sheep on each block were collected by means of harness and faecal bags as shown in Fig. 1.

Fig. 1.—Grazing rape by 16 wethers harnessed for total collection of faeces.

The organic matter intake of each sheep was then computed. The chemical composition of the rape consumed was determined from the composition and digestibility of the proximate constituents of the faeces, and the units of starch equivalents (s.e.) of organic matter calculated. The methods are given in the second paper of this series (Greenall 1958b). Live weights and weight gains were determined by weighing the sheep at the commencement and completion of grazing each block, after they had stood for 24 hours on gratings. The units of s.e. for maintenance and for weight gain of each sheep were calculated by the use of the feeding tables of Wood and Woodman (1930).

RESULTS

The layout of this part of the experiment is shown in Fig. 2.

Forty-eight separate measurements of live weight, weight gain, and intake of s.e. were obtained from the sixteen wethers grazing the three

Fig. 2.—The general layout of the experiment.

blocks. Correlation coefficients for intake and weight gain, for weight gain and weight, and for intake and weight, were found for these data and are recorded in Table 1.

TABLE 1. CORRELATION COEFFICIENTS

	Total	Sheep	Periods	Error
Intake and weight gain	0.5894**	0.8517**	0.9393	−0.1243
Weight gain and weight	0.2461	0.3583	0.9957	−0.4528*
Intake and weight	0.5573**	0.5603*	0.9670	0.4491*

* Significant at the 5% level of probability.
** Significant at the 1% level of probability.

The overall correlation of 0.59 between intake and weight gain is significant at the 1% level of probability and emphasises the major importance of intake on weight gain. As was expected, a correlation coefficient of similar magnitude and significance was found between intake and weight—heavier sheep eat more. For the totals of each sheep over all periods, the correlation coefficient for intake and weight gain and for intake and weight were 0.85 and 0.56 respectively. The corresponding correlation coefficients between period totals were 0.94 and 0.97. There was also a correlation of 0.99 for weight gain and weight of sheep between periods—weight gains were greatest in the periods when the sheep were the heaviest. These correlations were not significant as they had only one degree of freedom. From the "error" coefficients it may be concluded that there were significant, though not strong, tendencies for changes in intake and weight to be associated, apart from the sheep and period differences, and also for gains in weight to be greater when weights were lower. The heaviest sheep ate most and put on the most weight, but individually they gained more during periods when their weights were low.

From established principles and the magnitude of these correlations it follows that it is reasonable to attempt to predict intake from the equation $I = K_1 W^{0.67} + K_2 G$

where I = intake of s.e. — lb per day.

K_1 = a constant depending on the daily energy requirements for maintenance of weight.

W = live weight — lb.

K_2 = a constant — lb. of s.e. required per lb of live weight gain.

and G = live weight gain — lb.

Although this equation oversimplifies the relationship, the resulting error is not likely to be large. The constant K_1 would change very slightly over the normal range of sheep weights, the value decreasing with increasing weight. However, over the narrow range of weights of the wethers used, there was almost a straight line relationship between K_1 and W. Within this range K_1 varies directly with surface area which is usually expressed as $W^{0.67}$. It is known from respiration experiments and carcass assay that a curvilinear relationship exists between K_2 and W. The relationship is strictly between K_2 and stage of physiological development of which weight is a simple measure. With wethers of the weights employed, K_2 is known to increase with increasing weight, but it is considered that the assumption of a constant value of K_2 does not materially affect the result. Values for K_1 and K_2 were determined by multiple regression analyses of the forty-eight sets of data, and the following equation was derived:

$$I = 0.0753\ W^{0.67} + 1.1085\ G \text{ - - - - - - (1)}$$

TABLE 2. LB OF S.E. FOR MAINTENANCE AND WEIGHT GAIN OF YOUNG WETHERS DURING A 24-DAY PERIOD—STANDARD VALUES AND VALUES CALCULATED BY THE USE OF REGRESSION EQUATION (1)

Sheep No.	Live Weight Range – lb	Lb S.E. for					
		Maintenance			Weight Gain		
		Standard Values	Calculated Values	Diff.	Standard Values	Calculated Values	Diff.
5	98 –109	31.3	38.3	7.0	23.3	12.6	–10.7
6	88 – 87½	28.1	34.6	6.5	– 0.8	– 0.5	0.3
7	80 – 82	26.4	32.5	6.1	3.3	2.5	– 0.8
8	80 – 83½	26.6	32.8	6.2	5.8	4.2	– 1.6
9	87 – 99½	28.8	35.4	6.6	23.3	14.6	– 8.7
10	90 – 94½	28.8	35.5	6.7	8.5	5.3	– 3.2
11	85 – 90	28.0	34.4	6.4	8.6	5.8	– 2.8
12	85 – 86	27.7	33.9	6.2	1.8	1.3	– 0.5
13	82 – 90½	27.4	33.5	6.1	14.9	10.2	– 4.7
14	82 – 86	27.3	33.3	6.0	6.4	4.6	– 1.8
15	79 – 85½	26.3	32.5	6.2	10.7	7.7	– 3.0
16	75 – 79½	25.7	31.6	5.9	7.2	5.3	– 1.9
17	90 – 95½	29.0	35.8	6.8	10.0	6.2	– 3.8
18	81 – 87½	27.4	33.6	6.2	10.6	7.5	– 3.1
19	73 – 78½	25.1	30.8	5.7	9.1	6.8	– 2.3
20	81 – 88½	27.2	33.5	6.3	12.2	8.6	– 3.6
Mean	83.5– 89.0	27.6	33.9	6.3***	9.8	6.5	– 3.3***

*** Mean difference significant at the 0.1% probability level.

This equation contains separate terms for maintenance requirements and for weight-gain requirements, and although statistically the terms are not independent, it is of value to compute them separately.

Accordingly, the equation was used with the data on actual intakes, sheep weights and weight gains to compute s.e. for maintenance and for weight gain of each wether. The values obtained are recorded in Table 2, together with those calculated from Wood and Woodman (1930) feeding tables.

It is clear from this table that the maintenance requirements of s.e. for free-grazing sheep, as calculated from actual intake, were over 20% higher than standard values, the differences being greater for the heavier sheep. The average difference is significant at the 0.1% probability level. Conversely, the calculated s.e. requirements for weight gain were over 30% lower than standard values, this difference being also significant at the 0.1% level. The standard error of K_1 was 5% and of K_2 over 20%, due doubtless to inability to measure weight gain accurately during short periods of time, therefore, the same confidence cannot be held in the value for weight gain, as for maintenance.

The units of s.e. for maintenance, obtained from equation (1) and from standard values were plotted against live weight as shown in Fig. 3.

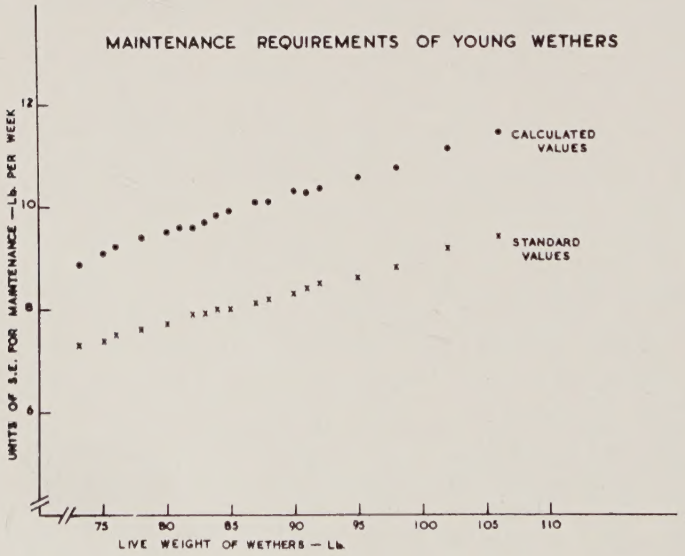

Fig. 3.—Maintenance values of young grazing wethers—calculated and standard values.

Not only are the calculated values higher than standard values, but also the difference increases with increasing live weight.

Equation (1) gave the best prediction of s.e. for maintenance and weight gain from actual intake, weight, and weight gain, in the sense that its biological meaning was clear. However, a more accurate pre-

diction of total intake of s.e. from weight and weight gain was obtained from the following multiple regression equation, derived from the same data as equation (1):

$$I = 0.1120\ W^{0.67} + 1.9310\ G - 0.8930 \text{ - - - - } (2)$$

where the symbols are the same as in the previous equation and 0.8930 is a further constant. In Table 3 is shown actual intake of s.e. by each wether for the 24-day period, as well as intake calculated from standard values and from equations (1) and (2).

TABLE 3. INTAKE OF S.E. BY SIXTEEN WETHERS DURING 24 DAYS PREDICTED FROM LIVE WEIGHT AND WEIGHT GAIN BY THE USE OF WOOD AND WOODMAN FEED TABLES AND TWO REGRESSION EQUATIONS

Sheep No.	Actual Intake	Standard Values	Actual — Standard Diff. %	Equation (1)	Actual — Equation (1) Diff. %	Equation (2)	Actual — Equation (2) Diff. %
5	52.0	54.6	− 5	50.9	+ 2	57.5	−14
6	29.6	27.3	+ 8	34.1	−15	29.3	+ 1
7	32.6	29.7	+ 9	35.0	− 7	31.3	+ 4
8	40.8	32.4	+21	37.0	+ 9	34.8	+15
9	58.8	52.1	+11	50.0	+15	56.8	+ 3
10	45.8	37.3	+18	40.8	+10	40.6	+11
11	44.8	36.6	+18	40.2	+10	39.9	+11
12	26.2	29.5	−13	35.2	−34	31.1	−19
13	52.7	42.3	+20	43.7	+17	46.3	+12
14	33.2	33.7	− 2	37.9	−14	36.1	− 9
15	38.6	37.0	+ 4	40.2	− 4	40.4	− 5
16	29.8	32.9	−10	36.9	−24	34.8	−17
17	43.3	39.0	+10	42.0	+3	42.6	+ 2
18	39.8	38.0	+ 5	41.1	− 3	41.7	− 5
19	35.8	34.2	+ 4	37.6	− 5	36.2	− 1
20	39.3	39.4	0	42.1	− 7	43.6	−11
	40.18	37.25	6.1†	40.29	− 2.9	40.18	− 1.4
				± 2.56		± 2.53	
Mean‡ error			9.9		11.2		8.7

† Mean bias significant at the 2% probability level.

‡ Ignoring sign of the difference.

It will be seen that equation (2) gives the best prediction of the mean intake, equation (1) is intermediate, and standard values provide the poorest prediction. Apart from this bias, however, individual errors from standard values only slightly exceed those from equation (2) and individual estimates from equation (1) are more variable.

The difference between actual intake and intake predicted from equation (2) are smaller than found by Wood and Capstick (1926) for data from sheep fed in metabolism cages. Actual intake was over 8% higher than predicted from standard values, a difference which is significant at the 2% probability level.

Farmers generally agree that lambs gain weight at a faster rate as the time during which they have been grazing rape increases, an observation which is largely confirmed by the results of Ewer and Sin-

clair (1951) and of this experiment. The most likely explanation is that level of intake increases with increasing time on rape, an explanation which is supported by the data in Table 4.

TABLE 4. INTAKE OF SIXTEEN WETHERS FOR THREE EIGHT-DAY PERIODS IN LB S.E. PER LB LIVE WEIGHT

Sheep No.	Block II	III	IV	Sheep Mean
5	0.116	0.197	0.193	0.169
6	0.108	0.116	0.115	0.113
7	0.122	0.136	0.148	0.135
8	0.145	0.184	0.175	0.168
9	0.185	0.240	0.222	0.216
10	0.153	0.158	0.191	0.167
11	0.163	0.174	0.182	0.172
12	0.093	0.097	0.117	0.102
13	0.207	0.206	0.213	0.209
14	0.121	0.134	0.144	0.133
15	0.138	0.153	0.192	0.161
16	0.128	0.129	0.134	0.130
17	0.134	0.171	0.183	0.163
18	0.159	0.128	0.187	0.158
19	0.156	0.181	0.151	0.163
20	0.135	0.166	0.170	0.157
Block Mean	0.141	0.161	0.170	

Analyses of Variance

Variance due to	df.	s.s.	m.s.
Blocks	2	0.006803	0.003402**
Linear	1	0.006528	0.006528**
Other	1	0.000275	0 000275
Sheep	15	0.040384	0 002692**
Error	30	0.007747	0.000258

** Significant at the 1% probability level.

It is clear from the analysis of variance that the level of intake of sheep was different for blocks at the 1% level of significance, but that this difference could be accounted for almost entirely by increasing intake as grazing progressed from Block II onwards. There were also large and consistent differences, which were significant at the 1% probability level, in the intakes of different sheep. To agronomists concerned with the most efficient utilisation of crop forages this poses several questions.

DISCUSSION

In several experiments in which free-grazing lambs grazed rape, Ewer and Sinclair (1951) recorded weight gains ranging from 0.16 to 0.47 lb per day. The mean daily weight gain of the wethers in this

experiment was 0.20 lb. The mean daily weight gain on Block I was nil, on Block II 0.18, Block III 0.23, and Block IV 0.32 lb. The increased rate of gain with successive grazing periods is in accord with the results of Ewer and Sinclair and is probably related to the progressively higher intake levels discussed above.

It was also noted that dry matter consumption per sheep over the period averaged 53 lb as against the 66 lb expected. The low values of mean daily weight gain and mean dry-matter consumption were almost certainly in large part due to starving the wethers for one day in each eight on gratings, and to disturbance due to harness and penning for faecal collection. Meyer *et al.* (1956) also recorded an adverse effect of harness on weight gain of grazing animals.

Regression equation (1) expressing the relationship between intake, maintenance and weight gain gave requirements of units of s.e. which differed substantially from standard values. There was reasonably good agreement between intake calculated by the use of these values and actual intake, although agreement was better with equation (2) which has an additional constant. Consequently, it seems likely that, for young wethers free-grazing rape, predictions of intake based on equation (2) are likely to be more reliable than predictions based on the standard values. Equation (1) should also yield good predictions. However, while confidence can be held in values calculated for maintenance this is not so for units of s.e. calculated to be required for weight gain. For the reasons stated, the value is likely to be too low, though in this experiment increments in weight may have been due to growth rather than fattening. In this case the calculated values would be less than 30% lower than standard values. It seems reasonably certain that the requirements for maintenance and production of sheep grazing rape *in situ* in this experiment were larger than those suggested by standard values. This is in accord with the results of Wallace (1956) for dairy cows on pasture.

There was evidence that level of intake was a factor of importance in productivity of wethers on rape; this is supported by Phillips (1936) who pointed out that there are large variations in live-weight gains of ruminants due to variation in appetite. There was also some indication of differences in the efficiency of conversion of rape into meat. This agrees with the work of Botkin (1955), who suggested there is scope for selection for efficiency of gain in lambs, while Hooven (1957) stated that, in dairy cows, efficiency of feed utilisation is inherited separately from high productivity, and could provide an additional basis of selection.

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THE TRANSMISSION OF *Phoma lingam* (Tode) Desm. IN THE SEEDS OF SWEDE, TURNIP, CHOU MOELLIER, RAPE, AND KALE

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(*Received for publication, 8 April 1959*)

Summary

In 1957 and 1958 a survey was made of the seed-borne infection of *Phoma lingam* in swede, turnip, chou moellier, rape, and kale seeds. Of the 263 seed samples tested, 223 were free from seed infection. Most of the samples with diseased seed had less than 0.1% infection. Details are given of a technique for detecting seed-borne infection of *P. lingam* in brassicas. The seeds were surface sterilised and placed on tap-water agar in petri dishes with 2,000 p.p.m. acid equivalent of 2,4-D in the medium, and the dishes incubated at 23°C for 12 days.

Approximately half the infected seeds did not germinate. Most of the seed infection was transmitted in the smallest seeds, and many of these were removed during seed-cleaning operations. The fungus remained viable in stored seed for about 14 months, beginning to die after 8 months storage.

The importance of seed-borne infection for primary spread of the pathogen is not supported by experimental work described, and air-borne infection is suggested as a new approach for further investigational work on the primary spread of *P. lingam*.

Introduction

Dry rot, caused by the fungus *Phoma lingam* (Tode) Desm., is a major disease of swede and turnip crops in New Zealand. When conditions are favourable for infection and for spread of the pathogen, complete losses can occur in swede crops, and in turnip crops, where the disease is less severe, part of the crop may be lost through diseased bulbs. In rape, kale, and chou moellier, the pathogen may form leaf and stem lesions, but is not considered a major disease.

The first record of the transmission of the pathogen in seed was made by Cunningham (1927). He tested 11 commercial lines of swede seeds by the agar-plate method and found 6 having diseased seeds with infection varying from 0.1% to 3.5%. These lines were probably imported English seed, as it was not then the practice to harvest brassica seeds in New Zealand. Cunningham concluded that, as there was no evidence of soil- or air-borne infection, the seed-borne phase was vital for control of the disease. Recently, Smith (1956) has described an air-borne sexual phase of the pathogen. Perithecia, containing spores capable of becoming air-borne and causing infection of swedes, were found on the refuse of old brassica crops.

Methods for controlling dry rot by sowing disease-free seed have been advocated in Britain (Noble 1951) and New Zealand (Blair 1952). New Zealand-grown seed had been tested regularly prior to 1956 and found to be free from infection (Smith 1956). In spite of this result,

seed-borne infection has been considered important where outbreaks of the disease have occurred in crops grown on land that has not previously supported a brassica crop.

Phoma lingam Survey

Sweed and turnip seed surveys for *P. lingam* in Britain (Buddin 1934) and Ireland (Hughes 1933) have shown that about one quarter of the samples tested in both countries had seed infection, but that this infection was very low, rarely exceeding 0.2% in any sample. Prior to the beginning of this present investigation, the seed-borne transmission of the pathogen in New Zealand-grown seed has been considered an important method for the spread of the disease, although it was conceded that seed infection must have been very low to have evaded detection by the methods used at that time.

Machine-cleaned lines of certified or Government-approved brassica seeds from crops harvested in 1957 and 1958 were used for a seed-disease survey. The age, area of growing and history of the seed were known through departmental certification records. These samples were tested soon after harvest as it was not known how long the fungus would remain viable in the seed. Imported seed samples and commercial samples of unknown age and mainly of uncertified origin were obtained from several merchants in 1957 and also included in the survey.

Initially Cruickshank's (1957) prune-agar plate method for the examination of pea seeds was modified for the testing of brassica seeds. This method was soon abandoned, as the seeds germinated on the nutrient-agar substrate and examination of the plates was difficult because of masking by the seedling growth. Finally it was decided to use a modification of the method of Hagborg *et al.* (1950), using the sodium salt of 2,4-D to inhibit the germination of the seeds. This had already been recommended as a routine technique by the International Seed Testing Association Committee on Plant Diseases.

Each sample of seed was mixed and mechanically divided until the sub-sample was reduced to approximately 1,000 seeds in 1957 and 3,000 seeds in 1958. The sub-sample was dipped in 70% ethyl alcohol as a wetting agent, and surface-sterilised for one minute in a sodium hypochlorite dairy disinfectant (10.2% w/w free chlorine). The seeds were washed in running tap water and air dried on filter paper. Seed germination filter-paper pads were soaked in a 0.2% solution of the sodium salt of 2,4-D and 100 seeds plated on to each pad by using a mechanical counter. The pads were put into petri dishes and placed in a high-humidity seed germinator with a glass door to admit light. After 12 days incubation at approximately 23°C, the plates were examined under a stereo-microscope for the presence of diseased seed. Pycnidial fructifications were observed on both ungerminated seed (Fig. 1) and abnormal seedlings (Fig. 2) where growth had been affected by the 2,4-D solution. Spores from the pycnidial exudate were measured under a high-power microscope. In 1957 all the dry-rot fungal colonies from infected seeds were sub-cultured on starvation potato-dextrose agar slopes, and pathogenicity tests made on either swede bulbs or choumoellier stems.

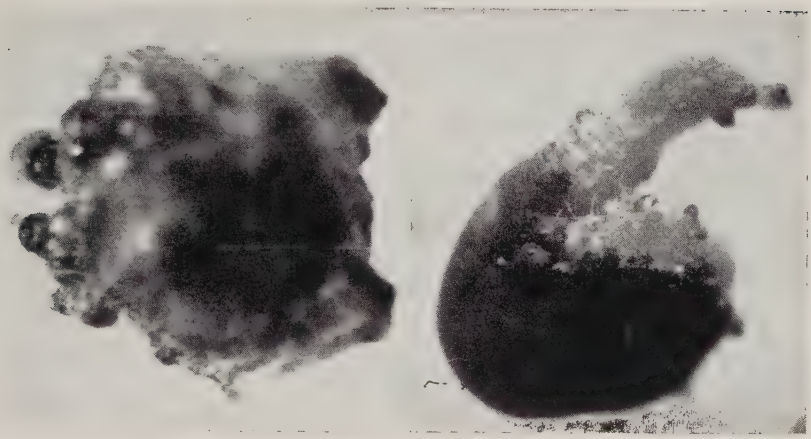

Fig. 1 Fig. 2

Fig. 1.—Ungerminated seed with pycnidia and mycelium on the seed coat.

Fig. 2.—Pycnidia on an abnormal seedling where growth has been restricted by the 2,4-D.

Table 1 shows the result of the seed-disease survey. The certified and Government-approved 1957 and 1958 samples were tested soon after harvest. Imported and commercial samples were obtained from several seed merchants and the age of the seed was therefore unknown, but they would be older than the certified and Government-approved seed. The extent of infection in the diseased samples ranged from 0.02% to 0.6%. Most of these samples had less than 0.1% infection, i.e. less than one seed in 1,000 seeds was infected. All brassica species examined had some infected seed, and pathogenicity tests on swede bulbs or chou-moellier stems were positive.

The 1958 samples were from seed crops grown during a wet season. Heavy infection in some of the swede and turnip bulbs, and a few observable lesions on the seed pods were reported during field crop inspections. Although conditions seemed to have been favourable for the spread of the disease, seed infection was little different from that found in the 1957 samples.

Artificial Inoculation of Seed

Throughout the survey no sample with a high seed infection was found which could have been used for further work on the reliability of the 2,4-D test. In 1957, seed was collected from York Globe turnip, Red Globe turnip and Grandmaster swede crops, all of which were heavily infected with dry rot. The turnip seeds were from crops reported as having a 100% dry-rot infection of the bulbs, and lesions on the stems close to the ground, but no noticeable lesions on the seed pods. In the Grandmaster swede crop there was a 100% infection of bulbs and a few lesions were seen on the seed pods. The three samples were tested by the 2,4-D method, no infection being recorded in the

TABLE 1. INCIDENCE OF *Phoma lingam* IN BRASSICA SEEDS

	No. of Samples Examined	No. of Samples in each Infection Class				
		0.0%	<0.1%	0.1%	0.2%	>0.2%
Swede						
Govt. Approved						
1957	11	7	2	1	1	
1958	11	6	4		1	
Imported U.K.	4	4				
Turnip						
Govt. Approved						
1957	19	19				
1958	40	32	5	3		
Chou moellier						
Certified 1957	17	15	2			
Certified 1958	40	33	7			
Commercial	28	24		2	1	1
Imported U.K.	8	7		1		
Impt. Australia	13	12		1		
Rape						
Certified 1957	19	15		3	1	
Certified 1958	28	25	3			
Imported U.K.	1	1				
Kale						
Certified 1957	4	4				
Certified 1958	5	4		1		
Commercial	5	5				
Imported U.K.	10	10				
Total	263	223	23	12	4	1

turnip samples and only 0.05% infection in the swede sample. As the heavily diseased seed crops yielded little or no infected seed it was decided to obtain diseased seeds by artificial inoculation.

Spore suspensions were made from cultures of *P. lingam* grown on Cruickshank's (1953) autoclaved pea-seed medium. The suspension was poured on sterilised filter paper in petri dishes and kept for about four hours at room temperature. Swede and turnip seeds were washed in running tap water, immersed in a spore suspension, drained, and spread evenly over the wet filter paper in the petri dishes. After incubation for about 14 hours at 25°C the seeds were removed to fresh paper pads and dried in a warm oven. Subsequent seed-disease tests showed that about 10% of one line of seeds were artificially infected with *P. lingam*. This seed line was used for all trials testing the 2,4-D method.

EXAMINATION OF BRASSICA SEEDS FOR *Phoma lingam*

It was found necessary to surface-sterilise seeds to eliminate external seed-borne saprophytic fungi, which if present, could mask the slow-growing dry-rot fungus. A trial to determine if it would be feasible to dispense with surface sterilisation was carried out at the beginning of 1958, and it was found that some saprophytic *Phoma* species were difficult to differentiate from the dry-rot organism. The necessity for the continuation of surface sterilisation was therefore demonstrated. The test is used for detecting internal seed-borne infection. If external seed-borne infection did occur, it could be controlled by dusting the seed with a fungicide, a practice now in operation for all Government-approved swede and turnip seeds.

Tap-water agar was found to be a more satisfactory substrate than seed-germination pads. The sodium salt of 2,4-D was added to the tap-water agar before autoclaving, and the medium poured into sterile petri dishes. This method had the advantage of a more even control of moisture and, the substrate being sterile, reduced the chances of masking by saprophytic contaminants. The dry-rot fungus grew and formed characteristic colony growth on the agar (Fig. 3), although pycnidial development was mainly confined to the seed coat (Fig. 4).

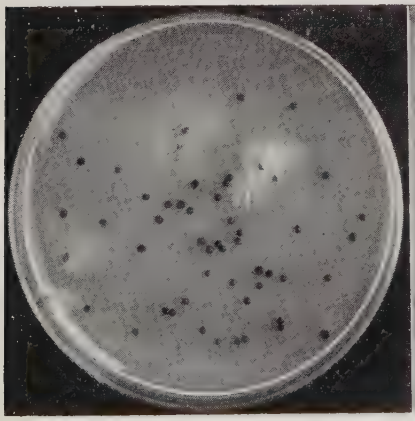

Fig. 3

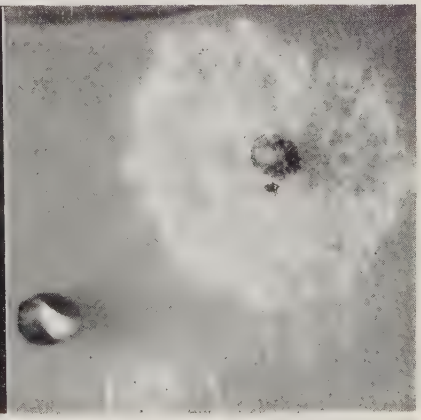

Fig. 4

Fig. 3.—Colonies of *P. lingam* developing from infected seeds.

Fig. 4.—A single colony growing from an infected seed. Pycnidia confined mainly to the seed coat.

Fungi vary in their tolerance to 2,4-D in the medium. Bever and Slife (1948) reported the killing of *Pythium debaryanum* at dilutions between 250 and 2,000 p.p.m. acid equivalent of the 2,4-D, but found that, with the other two fungal pathogens used for the test, growth was retarded in proportion to the dilutions. Hagborg *et al.* (1950) reported that *Colletotrichum lindemuthianum* was retarded in growth with concentrations of 2,4-D above 100 p.p.m. acid equivalent. A series of dilutions from 200 to 4,000 p.p.m. acid equivalent, using tap-water agar

without 2,4-D as a control was made to find its effect on the growth of *P. lingam*. Although this organism does not grow strongly on tap-water agar, it does form large enough colonies for observational purposes. After 12 days incubation, the colonies averaged 4 cm in diameter with all concentrations up to 1,000 p.p.m., 3.5 cm at 2,000 p.p.m., and 2.5 cm at 4,000 p.p.m. acid equivalent. Brassica seeds were plated on a similar series of dilutions of 2,4-D in tap-water agar to determine the lowest dilution which would retard germination of the seed. It was found that at 2,000 p.p.m. acid equivalent, the seed coats were generally broken but germination did not often proceed beyond the stage where the cotyledons and radicle started to emerge from the seed coat. With concentrations below 2,000 p.p.m. the seeds germinated, although producing abnormal seedlings.

There are conflicting reports on the importance of light for growth rates and pycnidial development of *P. lingam*. Cunningham (1927) could not find any measurable differences between cultures grown with or without light. Buddin (1934) recorded higher infection in seedlings grown with light and Dennis (1939) found that by placing seedlings under a south window so that they received maximum direct sunlight he was able to record a higher percentage of infected seedlings.

A comprehensive trial was carried out (Table 2) to determine the effect of surface sterilisation, light, and 2,4-D in the technique for determining seed-borne infection. Three methods of seed surface sterilisation were compared, including the method used in the seed-disease survey for a control:

1. Seeds dipped in 70% ethyl alcohol and surface sterilised for one minute in 100% sodium hypochlorite dairy disinfectant.
2. Seeds dipped in 70% ethyl alcohol and surface sterilised for 5 min in 20% sodium hypochlorite dairy disinfectant.
3. Seeds immersed for 5 min in 0.1% solution of mercuric chloride with "Teepol" included as a wetting agent.

Seeds were plated on tap-water agar in petri dishes, with a concentration of either 2,000 p.p.m. or 10,000 p.p.m. acid equivalent of 2,4-D in the medium. The petri dishes were put in a glass-door germinator in a room with a high light intensity. Half the number of petri dishes were kept in darkness by wrapping them in brown paper. The plates were incubated at 23°C for a period of 12 days and the seeds then examined for the production of *P. lingam* colonies. The trial was replicated, 500 seeds being plated for each treatment.

Table 2 shows the number of infected seeds recorded with different light and surface-sterilisation treatments. Means are also given as the agreement between replicates was within limits for all treatments. In the dark there was no significant difference between the three methods of seed surface sterilisation. The two sodium-hypochlorite treatments in the light were significantly higher than all other treatments. No *P. lingam* colonies were observed on the tap-water agar medium with 10,000 p.p.m. acid equivalent of the sodium salt of 2,4-D, and these results were therefore not recorded in this table.

TABLE 2. NUMBER OF INFECTED SEEDS RECORDED WITH DIFFERENT LIGHT AND SURFACE-STERILISATION TREATMENTS

Surface Sterilisation	Replicate	Light	Dark
100% Sodium hypochlorite dairy disinfectant	1	48	33
	2	51	35
20% Sodium hypochlorite dairy disinfectant	1	52	33
	2	52	31
0.1% Mercuric chloride	1	30	35
	2	39	35
Mean		45	34

EFFECT OF THE PATHOGEN ON SEED GERMINATION

Early seedling infection from the planting of infected seed has been suggested as an important method for the spread of the disease (Butler and Jones 1955). The mycelium is mainly confined to the seed coat (Cunningham 1927; Hughes 1933), the young seedling being infected when the seed coat is carried to the tip of the cotyledons during the process of germination.

Seed-borne infection had been found in New Zealand seed but it was not known what percentage of these infected seeds would germinate. Seedlings were grown on seed-germination tanks in a room with a high light intensity from overhead windows. The seedlings were grown on continuously moistened filter-paper pads covered with glass bell-jars. Lesions were observed on some of the cotyledons and stems. Many of these lesions appeared sterile, while some others were caused by *Alternaria* species. A few dry-rot lesions were found but the number was so small that the method was abandoned as being unreliable. Buddin (1934) and Dennis (1939) placed great reliance on this method, both of them considering that light was important for the development of pycnidia.

It has already been shown that pycnidia would develop on infected seeds plated on an agar substrate, and this method was adopted for the detection of seedling infection. A line of Calder swede and one of Purple Globe turnip, known to have seed infection, were sub-sampled until 5,000 seeds were obtained from each. Seeds were germinated and grown on moist filter paper until the cotyledons were well developed. The seed coats, cotyledons, and any ungerminated seeds were transferred to a tap-water agar substrate in petri dishes. Forceps were flamed to prevent any cross-infection during transference. The petri dishes were put in a germinator and incubated at approximately 23°c for 12 days. Where there were observable symptoms of wilting the whole seedling was put on the tap-water agar substrate. In a few cases the seed coat is not carried to the top of the seedling by the cotyledons, but remains attached to the hypocotyl and infection starts in the hypocotyl region, causing the wilting symptoms. Abundant pycnidia occurred on some of the cotyledons and on ungerminated seeds. The

empty seed coats were a poor substrate for the development of pycnidia, as only a few were observed and these were small and black with no spore exudate. The swede sample had infections on 21 cotyledons and 19 ungerminated seeds and the turnip sample on 5 cotyledons and 6 ungerminated seeds. The results of this trial showed that about half the infected seeds did not germinate. It is possible that, under favourable conditions for pycnidial development, the ungerminated seeds could spread infection in the field crop, although it seems unlikely that infected dead seed lying on or in the soil would transmit the disease to other plants.

Removal of Infection by Seed Cleaning

The seed-borne infection is small in machine-cleaned brassica seeds, but it was not known what infection, if any, had been removed during the seed-cleaning operation. Lines of Purple Globe turnip, Crimson King swede, and Calder swede, each known to have infected seed, were obtained for trials on this work. The seed-cleaning firm which cleans Government-approved swede and turnip seeds, supplied samples of machine-cleaned seed, and seconds (seed cleanings) from the three lines. Each seed sample was randomly divided until it was reduced to a sub-sample of 5,000 seeds, and these were tested for infection by the 2,4-D tap-water agar method. The turnip sample had 21 infections in the machine-cleaned seed and 43 infections in the seconds, the Crimson King swede 0 and 5, and the Calder swede 17 and 45.

Machine-cleaned lines of seed were separated into several grades of seed size by the use of hand sieves, and each grade tested for seed infection. The highest infection was recorded in the smallest seeds, although there was some infection in the largest seeds. From these trials it appears that machine cleaning does reduce the number of infected seeds in a line, but as seed-borne infection can be transmitted by the largest seeds, it seems unlikely that all infection could be removed from swede and turnip seed lines by normal seed-cleaning methods.

Viability of the Fungus in Stored Seed

Two samples of swede seeds from crops harvested in Central Otago during February 1957 were tested at intervals until no infection could be detected in either line of seed. The machine-cleaned samples were collected and kept in a seed store during the time of the trial. Seed-disease tests were made on the samples by the 2,4-D tap-water agar method, using 5,000 seeds from each sample.

TABLE 3. Number of Infected Seed Recorded During Storage

	Months of Storage						
	6	8	9	12	14	17	18
Sample 1	10	10	5	4	0	0	0
Sample 2	12	10	6	2	1	0	0

Table 3 shows the number of infected seeds recorded in each test. From these results it appears that the fungus tended to die somewhere between 8 and 17 months in storage. It was further shown that there was no infection in any of 17 samples of swede seed varying from 2 to 5 years in age, when these samples were tested for seed infection. Very little swede and turnip seed is sown within a period of 10 months between harvesting and spring sowing of the seed. With Government-approved swede and turnip seed, it is the aim of the Department of Agriculture to withhold each year a full reserve of seed as a precaution against seed-crop failures. Much of the Government-approved seed will therefore have been harvested a period of 22 months before it is sown, a practice which is to be recommended as a result of these trials.

DISCUSSION

Seed-borne infection of the dry-rot organism has been considered an important method for primary spread of the disease in swede and turnip crops. The experimental work described does not support this theory for the following reasons:—

1. In newly harvested machine-cleaned swede and turnip seeds, infection was extremely low.
2. Approximately half the infected seeds did not germinate.
3. The fungus begins to die in seed after eight months storage

Field observations have shown that dry-rot outbreaks can occur in swede and turnip crops growing on land that has not previously been planted in a brassica crop. Frequently, seed-borne infection is suspect, but the experimental work presented does not support this theory. Smith's (1956) report on an air-borne infection suggests a new approach for further investigational work on the primary spread of *Phoma lingam*.

ACKNOWLEDGEMENTS

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EFFECT OF PHOSPHATE TOPDRESSING ON A SOIL FROM ANDESITIC VOLCANIC ASH

III. PHOSPHATE RETENTION AND pH

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Summary

pH-phosphate retention curves have been obtained for a yellow-brown loam, the New Plymouth black loam, at low, moderate and high phosphorus status. These curves show that in these moderately acid soils exchangeable calcium plays no part in phosphate retention and that the large capacity of this soil to retain added phosphate is due to a high content of active aluminium. The most probable source of this active aluminium is the amorphous clay mineral allophane AB which is the dominant clay mineral of this soil.

Introduction

In Part II of this series (Saunders 1959b), it was shown that phosphate topdressing on the New Plymouth black loam brought about a large increase of Fe- and Al-bound phosphorus, and a small accumulation of apatite phosphorus in the surface two inches of the soil. It was concluded that the accumulated apatite phosphorus was the residue of rock phosphate added in the fertiliser and not the result of fixation by calcium. This conclusion was based upon the soil being moderately acid with high content of clay and "free" sesquioxide, under which conditions exchangeable calcium is not considered to retain added phosphate. Further evidence for this conclusion was obtained from pH–phosphate retention curves which also gave information on the parts played by iron and aluminium in retaining phosphate in this soil. These curves are discussed below.

Soils and Methods

The soils used in this work have been described in Part II. Briefly, the New Plymouth black loam is a yellow-brown loam derived from the fine-textured andesitic volcanic ash which covers most of the Taranaki province. Three pairs of soils were collected. They were: a pair from untopdressed sites (No-P); a pair from fields which had received phosphate at a moderate rate, 20–30 lb P/acre for 25 years (Mod-P); and a pair which had been topdressed only comparatively recently but at a high rate, 60–80 lb P/acre for 8 years (Heavy-P). Because the effect of phosphate topdressing was confined mainly to the 0–2 in. layer, the pH-phosphate retention curves have been determined only on the 0–2 in. samples.

The pH–phosphate retention curves were obtained by the procedure used by Mattson *et al.* (1950). Two grammes of air-dry soil were shaken for 18 hours with 100 ml of solution containing phosphate as KH_2PO_4 at the rate of 43.6 mg P/100 g air-dry soil and varying

amounts of 0.1 N NaOH or HCl to adjust the pH. After shaking, the pH of the suspension was measured and the suspension filtered. Phosphate was determined colorimetrically (Williams and Stewart 1941) on an aliquot of the filtrate.

Results and Discussion

In the discussion of phosphate retention in Part I of this series (Saunders 1959a), it was pointed out that maximum retention of phosphate by iron, aluminium and calcium occurred within certain pH ranges. The upper limits of the maximum phosphate retention vary with the ratio P : cation, but the lower limits are more definite. They are pH 2.0–2.5 for iron, 3.5–4.0 for aluminium, and 6.0–6.5 for calcium. Bearing in mind these lower limits, the shape of the pH–phosphate retention curve for a soil can indicate which of the three elements is present in a form and in sufficient amount to retain added phosphate. The curves do not, however, show the native distribution of phosphate among the three elements.

In Fig. 1 are shown the curves for the No-P, Mod.-P and Heavy-P soils. Each curve is drawn from the points obtained from the pair of soils at each phosphorus level. The agreement within each pair was excellent.

For all three pairs of soils maximum phosphate retention occurs between pH 4 and 5. At this pH there is a little more phosphate in solution in equilibrium with the Heavy-P soils than with the Mod.-P or No-P soils. Above pH 5, for all the soils, the amount of phosphate in solution increases rapidly as the capacity of the soils to retain phosphate decreases. As far as pH 7 there is a little more phosphate in solution above the Heavy-P soils than above the Mod.-P and No-P soils but the difference is small. Above pH 7 the curves are indistinguishable.

There is no suggestion of a phosphate retention maximum at about pH 6.5 to 7.0 which would occur if calcium was active in retaining phosphate (Mattson *et al.* 1953). It is evident that, although calcium is present as an exchangeable cation in relatively large amounts (30 me.% in the Heavy-P soils), it is held too strongly by the cation exchange complex for it to be available to retain phosphate. This is in agreement with the results of Mattson (1953) who found that, unless the cation exchange complex was practically saturated with calcium, phosphate retention by calcium did not occur. The effect of active calcium on the shape of the pH-phosphate curves can be seen in Fig. 2 which was determined using one of the No-P and one of the Heavy-P soils and added 20 and 200 me.% of Ca as $CaCO_3$. The addition of $CaCO_3$ has considerably decreased the amount of phosphate in solution above pH 5 for both soils, and where 200 me.% of Ca was added there is a distinct phosphate retention maximum at pH 6.5–7.0, especially for the Heavy-P soil. The marked difference between the curves with and without added calcium support the conclusion that calcium plays no part in retaining phosphate in these soils.

Referring back to Fig. 1, between pH 4 and 5 the curves for the No-P, Mod.-P, and Heavy-P soils lie close together, but below pH 4

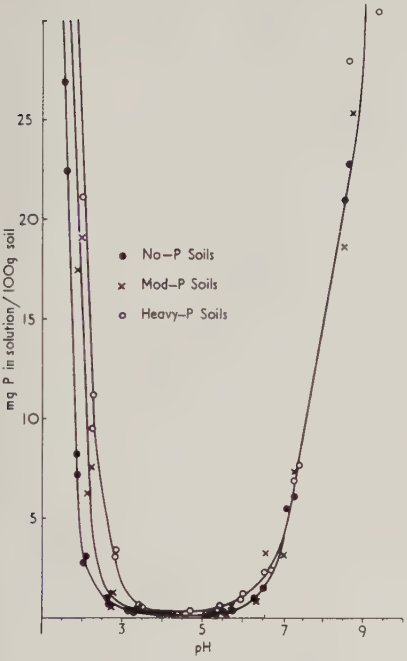

Fig. 1

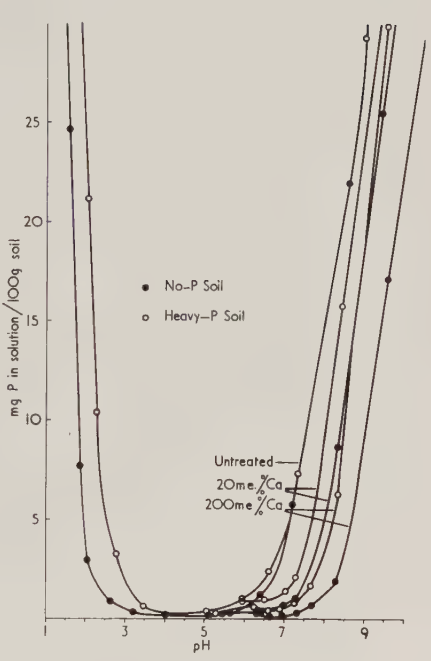

Fig. 2

Fig. 1.—Retention of phosphate by the No-P, Mod-P, and Heavy-P soils, as a function of pH.

Fig. 2.—Retention of phosphate by a No-P and a Heavy-P soil, with and without added calcium, as a function of pH.

the three curves begin to separate. The curve for the Heavy-P soils shows a rapid decrease in phosphate retention at pH 3.5. For the Mod.-P soils this decrease occurs at pH 2.8, and for the No-P soils at pH 2.5. The differences between the amount of phosphate in solution over this portion of the retention curve are very much greater than the differences occurring above pH 5 and therefore it is most improbable that they are due solely to the higher phosphorus content of the Heavy-P and Mod.-P soils. It is suggested that the major reason for the separation of the curves below pH 4 is due to there being very much more aluminium than there is iron available to retain added phosphate.

As the pH of the soil-phosphate systems is lowered below pH 4, there would be a gradually increasing dissolution of Al-bound phosphorus, but retention of phosphate by iron would be approaching its maximum: and hence, when there is sufficient active iron in the system, the phosphate released from aluminium binding is retained by iron. This has occurred in the No-P soils where the release of phosphate does not occur until pH 2.5, the pH where dissolution of Fe-bound phosphorus begins.

In the Heavy-P soils, however, there has clearly been more phosphate released from aluminium than could be retained by the iron, and a rapid increase of phosphate in solution below pH 3.5 has occurred. In the Mod.-P soils, which do not have such a high phosphorus content as the Heavy-P soils, the rapid release of phosphate occurs at an intermediate pH, 2.8.

If sufficient active iron was present in the soils this separation of the curves below pH 4 should not occur. This point was tested by repeating the curves for one of the No-P and one of the Heavy-P soils with 53.5 me.% of Fe^{3+} added. The two curves are shown in Fig. 3. The addition of ferric iron has increased the retention of phosphate and at the alkaline end of the curve has extended the phosphate retention maximum from pH 5 to pH 6. At the acid end of the curve, the two curves, No-P and Heavy-P, are now very similar and the release of phosphate commences at pH 2.5. There is now sufficient iron in the Heavy-P system to retain phosphate released from aluminium between pH 4 and 3.5.

It is possible that the lack of active iron in the Heavy-P soils was due to its inactivation by combination with a component of the organic matter. To test this, a No-P soil and a Heavy-P soil were treated with

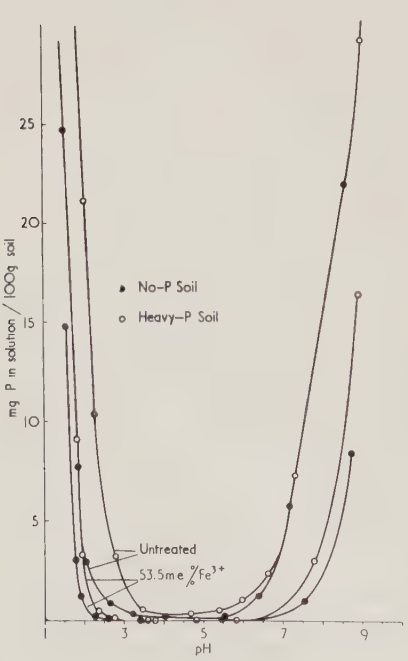

Fig. 3

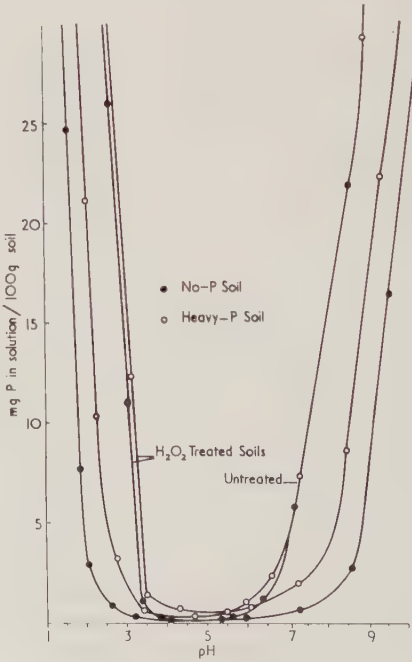

Fig. 4

Fig. 3.—Retention of phosphate by a No-P and a Heavy-P soil, with and without added ferric iron, as a function of pH.

Fig. 4.—Retention of phosphate by a No-P and a Heavy-P soil, before and after treatment with H_2O_2, as a function of pH.

H_2O_2 to remove organic matter. After boiling with H_2O_2 the suspensions were filtered and the soil residues washed with water. The soils were then air-dried at 35°c. This treatment resulted in a 25% loss of weight. Soil samples equivalent to 2 g of the original soil were then used to obtain the pH–phosphate retention curves shown in Fig. 4. The curves for the untreated No-P and Heavy-P soils are included for comparison.

When considering these curves two factors must be borne in mind. First the removal of organic matter may increase the capacity of the soil to retain phosphate and second, the destruction of the organic matter has released about 150 mg P % which is now present in the soils as inorganic phosphorus. The curves show that removal of the organic matter has considerably increased the phosphate retention capacity of the soil above pH 5, but at pH 4 to 5 the amount of phosphate in solution is similar in the untreated and the H_2O_2-treated soils despite the greater amount of phosphate in the latter systems. The phosphate-retention maximum for the treated soils extends to pH 6 as occurred when extra iron was added. Below pH 4 the curves for the two treated soils are very similar. There is a sudden release of phosphate at pH 3.5. The extra phosphate in the system derived from the destruction of the soil organic matter is more than can be retained by the iron even in the No-P soil. The inability of the soils to retain phosphate below pH 3.5 was not due to the extraction of iron from the soil by the H_2O_2 treatment. Analysis of the filtrate from the H_2O_2 treatment showed there to be only 0.015 and 0.012% Fe from the No-P and Heavy-P soils respectively, and 0.29 and 0.24% Al.

General Discussion

These pH–phosphate retention curves have shown well the parts played by calcium, iron, and aluminium in this soil, New Plymouth black loam. Although the soil contains a considerable amount of exchangable calcium it plays no part in retaining added phosphate even at pH 6.5–7.0, the range where maximum retention of phosphate by calcium can be expected. This maximum retention was shown by the curves when $CaCO_3$ was added. This is in agreement with Mattson *et al.* who concluded that, unless the cation exchange complex was almost fully saturated, exchangeable calcium was too firmly held to react with the added phosphate.

The decrease of phosphate retention above pH 5 suggests that an improvement of phosphorus status could be brought about by an increase in pH. This has probably been a contributory factor in the higher level of available phosphorus in the Heavy-P soils (pH 6.1) compared with the No-P soils (pH 5.8) (Saunders 1959b). However, this improved phosphorus status is not brought about simply by heavy liming which does not give a pasture response on this soil, even at rates of 2 tons/acre (Burgess and Davies 1951). A possible explanation for this lack of response may be found in the pH-phosphate curves where $CaCO_3$ is added. The addition of 20 me.% Ca (1% $CaCO_3$), which is equivalent to 1 ton of lime/2 in. acre of this soil, reduces the phosphate in solution above pH 5.0 and it is not until above pH 7 that

the phosphate in solution is equal to that for the untreated soils at the pH of the original soils, that is, 5.8 and 6.1 for the No-P and Heavy-P soils respectively. Therefore, to improve the phosphorus status it appears that liming would need to raise the pH above 7. As the yellow-brown loams as a group are strongly buffered soils, it is most unlikely that 1 ton lime/acre would do this. It is very rare in Taranaki to find a yellow-brown loam of pH as high even as 6.5. The similarity of the pH values of the No-P and Heavy-P soils, even though their base saturations differ considerably (% base saturation 50 and 80 respectively), is an example of this strong buffering action. It is possible that heavy liming of these soils is more likely to reduce the phosphorus status.

Iron and aluminium are the major agents retaining phosphate in this soil and it is very probable that there is a far greater amount of active aluminium present than there is iron. The mean value for the phosphate-retention capacity at pH 4 (Piper 1950) for the 0–2 in. samples is approximately 2800 mg P %, and this may be attributed to both iron and aluminium. This is a very high value compared with the figure of 110 mg P % which is the difference between the inorganic phosphorus content of the No-P and Heavy-P soils and which was all that was required to saturate the capacity of the iron in the soil to retain phosphate. Thus most of the large capacity of this soil to retain phosphate is probably due to aluminium. This is in accord with the conclusion drawn in Part II (Saunders 1959b), on the basis of the high solubility of the Fe- and Al-bound category of the soil phosphorus in neutral NH_4F, that this category of the soil phosphorus is mainly Al-bound. The most probable source of active aluminium in this soil is its dominant clay mineral, amorphous allophane AB (M. Fieldes, pers. comm.). Allophane AB is intermediate between the two forms of allophane identified by Fieldes (1955), allophane A and allophane B, and like these extremes is characterised by a very high surface area which allows a high proportion of aluminium to be on the surface and available for phosphate retention.

Acknowledgements

The author wishes to thank Messrs. A. C. Burgess and B. Gold for helpful discussion, and also to acknowledge the help of Dr. T. M. Morrison in the pot experiment described in Part II of this series. Dr. R. H. Jackman kindly provided the organic phosphorus values determined by the method of Mehta *et al.* shown in Table 1, Part I.

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THE EFFECT OF THYROXINE ON LACTATION IN EWES

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Summary

During the years 1955-57 inclusive measurements of growth rates have been obtained from some 289 lambs. Approximately half of these have been suckled on ewes implanted with l-thyroxine.

Growth rates of the lambs have been used to indicate the lactation level of the treated and control ewes.

Evidence of lactation response from the treated ewes has been obtained from (1) mature ewes implanted with thyroxine (a) six weeks before lambing, (b) two-three days after lambing, and (2) two-tooth ewes implanted about the time of mating.

Introduction

The contribution of the thyroid gland towards lactation in animals has been recognised for some time. Blaxter *et al.* (1949) in their comprehensive review of the literature dealing with the relationship of the thyroid to animal production refer to the effect on lactation achieved through the use of thyroxine as such, or in the iodinated protein form, on both goats and cattle but not sheep. As would be expected, a considerable volume of work has been directed towards an understanding of the effect of thyroxine on dairy cows, since Graham (1934a, b) first demonstrated that a response was obtainable. More recently Leech and Bailey (1953) in a large scale experiment involving over 2000 cows, treated with both iodinated casein and l-thyroxine sodium, were able to show an increase in milk yield. However there have been remarkably few reports in the literature on the contribution of the thyroid towards lactation in the ewe.

What appears to be one of the earliest experiments conducted with sheep is that of Neumann *et al.* (1950) who by feeding thyroprotein daily to lactating ewes and weighing their suckled lambs showed an increasing milk yield from the treated animals as determined by the live weights of their lambs.

Further evidence of the possible relationship between level of thyroid output and lactation in ewes is supplied by Singh *et al.* (1956) who report evidence suggesting that, among the ewes suckling twins, those with the higher thyroid activity tended to produce more milk when measured by the weight gains of their lambs, up to three weeks of age.

More recently Labban (1957) has shown that feeding thyroxine as a supplement to lactating ewes between the second and sixteenth weeks of lactation caused an increased rate of milk secretion. Many trials involving the use of thyroxine in various forms on sheep have been

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conducted continuously at Canterbury Agricultural College, Lincoln, since 1953, a considerable amount of emphasis being directed towards the increased rate of wool growth resulting from the daily injection of thyroxine into ewes (Hart 1953). However, the daily injection method of administration was discontinued with the success of the implanting technique developed the following year (Hart 1955). As the result of this some relatively large-scale field trials, basically designed to study wool-growth responses (Hart 1957; Coop and Clark 1958), were commenced in 1955. At the same time, measurements of rate of milk production on some of the treated and untreated sheep were also made.

The lactational aspects of these experiments, extending over a total period of three years, form the basis of this paper.

Experimental Methods

Implanting. The site selected was a point behind the shoulder and near the centre line of the back. This position is very accessible when sheep are held in a crush race and it is not necessary to hold individuals during the operation. The implants were made subcutaneously, employing an implanting gun, and doses were made up by using a single pellet containing 30 mg of l-thyroxine or multiples thereof.

Lactation. Owing to the nature of the trials it was not possible to measure the actual milk production of each ewe. However it has been previously shown by Wallace (1948), Hunter (1956), Labban (1957), and others, that the correlation between weight of lamb at weaning and the milk yield of the ewe is of the order $r = 0.8$. Thus for the purposes of these experiments weight of lamb expressed either as the total, or as gain per day, has been taken as the first measure of the ewe's level of lactation. Barnicoat *et al.* (1949) suggests a factor of 5.5 for converting lamb weight into milk production with Romney twins. Similar unpublished data derived from experiments at this College with Corriedale stall-fed ewes suckling twins, gives a factor of 7.5 over a twelve-week lactation. There is therefore more than sufficient evidence to warrant the use of lamb weights as a measure of the relative levels of milk production between groups. Because of breed differences, the use of conversion factors to determine total yield has not been deemed advisable in these experiments. The figures used were the weights of the lambs obtained at various intervals throughout the lactation period.

Procedures and Results

1955 Experiments

These were conducted on mature Corriedale ewes which were part of the flock run on the College light-land property at Ashley Dene. The plan of the experiment involved the constitution of two treated groups of ewes and one control group. All ewes had for recording purposes to be suckling twin lambs. The aim with the treated sheep was to have one group implanted six to eight weeks prior to lambing, and the second group as shortly after lambing as was practicable. Each ewe for the pre-lambing group was implanted on 29 June 1955 with 90 mg of thyroxine. Subsequent lambing dates showed this to have

been between 6–7 weeks prior to the ewes' actual mean date of lambing. As it was not possible to determine the proportion of ewes bearing twins at this stage, sufficient ewes were implanted, as it was thought at the time, to allow for the future constitution of a group of at least ten ewes suckling natural twin lambs. Subsequent lambing figures did not produce the expected number of twins for this group.

The groups for control and post-lambing implants were taken from the same mob of ewes as the pre-lambing implant group. They were constituted by selecting from untreated ewes those which lambed twins on or about the same dates as the pre-lambing treated group, the two groups being built up by alternate allocation of twin-bearing ewes in order of lambing. The implanting of 90 mg of thyroxine was done a day or two after each ewe had lambed and was mothering its lambs successfully—usually just as they were put on to the green feed. The final production of three groups of ewes, reasonably balanced for age, all suckling twin lambs was desired. Unfortunately, the percentage of twins occurring in the portion of the flock available was low during the 1955 season and the number of suitable ewes for the trials suffered accordingly. All three groups were grazed together in the same mob throughout the suckling period.

The mean group fortnightly weights and calculated rates of growth for the 1955 trials are contained in Table 1. Fig. 1 also shows the growth curves for each group in this year's experiments.

TABLE 1. Weights of Twin Lambs Suckled on Mature Corriedale Ewes (1955)

	Control 14 Lambs			Pre-lambing June Thyroxine Implant 8 Lambs			Post-lambing September Thyroxine Implant 10 Lambs		
Date 1955	Mean l.w. lb	l.w. age	Daily Growth Rate	Mean l.w. lb	l.w. age	Daily Growth Rate	Mean l.w. lb	l.w. age	Daily Growth Rate
14 Sep.	18.7	0.81	—	21.1	0.89	—	21.2	0.94	—
28 Sep.	24.2	0.71	0.52	26.0	0.77		30.9	0.84	0.69*
12 Oct.	31.5	0.65	0.52	34.5	0.79	0.61^{NS}	39.0	0.76	0.58
26 Oct.	40.9	0.65	0.66	43.8	0.75	0.67^{NS}	50.8	0.78	0.84*
9 Nov.	50.0	0.65	0.65	54.5	0.75	0.76^{NS}	62.4	0.79	0.83**
18 Nov.	54.0	0.62	0.44	59.3	0.73	0.54^{NS}	66.9	0.76	0.50
25 Nov.	56.7	0.61	0.39	62.1	0.70	0.40^{NS}	70.1	0.74	0.45

** Sig. diff. from controls $P < 0.025$
* Sig. diff. from controls $P < 0.05$
l.w. = live weight

It is fairly obvious that differences have been obtained in the rates of growth of the three groups of lambs. The magnitude of the difference has varied slightly from period to period as would be expected. Nevertheless, analysis of variance shows the differences to be statistically significant for several of the points.

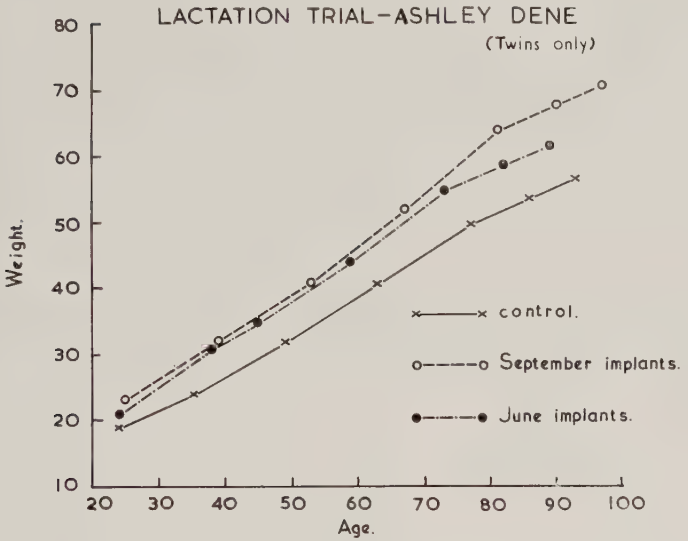

Fig. 1.—Growth curves of lambs in 1955 at Ashley Dene.

The average total live weight gained by each group between 14 September and 25 November is shown in Table 2. Both of the groups of lambs suckled on the thyroxine-treated ewes show fairly substantial total live-weight increases over those of the lambs suckled on the control ewes, the increases being significant at 10% and 2½% level for the pre-lambing and post-lambing implants respectively.

TABLE 2. MEAN LIVE WEIGHT GAINED BETWEEN 14 SEP. AND 25 NOV. 1955
(twin lambs suckled on mature ewes)

	Mean l.w. gain lb	Diff.
Control	40.5	—
June implant 90 mg	46.8	+ 6.3*
Sept. Implant 90 mg	48.9	+ 8.4**

* Sig. Diff. $P < 0.10$
** Sig. diff. $P < 0.025$

During the first half of the suckling period from 14 September to 26 October, average relative changes in the live weights of the ewes were as follows:

Controls	+ 13 lb
June implants	+ 15 lb
September implants	— 1 lb

1956 Experiments

These were conducted in a stud Romney breeder's flock where it has been the practice to collect detailed information on the performance of each ewe and her progeny for several years; thus the flock represented almost ideal material with which to experiment.

Two groups of ewes were made available by the owner of the stud, one consisting of mixed-aged ewes rising three-years old and upwards, and the other all rising two-year-olds going to the ram for the first time.

Both age groups were randomised into two groups, one for treatment with thyroxine and the other to act as a control. Implanting was carried out on 6 March 1956 prior to mating, both the mixed-aged and 2-tooth treated groups receiving three 30 mg implants totalling 90 mg per sheep. The numbers finally implanted were:

	Control	Treated
Mixed-age ewes	46	54
2-tooth ewes	60	55

Normal stud flock management was then followed with all the groups, the rams being run with the ewes from 17 March onwards.

Lamb weights were obtained for both twins and singles, although it was recognised that the most accurate lactation data are those produced by ewes suckling twins.

The number of weighings was reduced to three, these being taken at birth, tailing, and weaning, it being considered that these three figures give sufficiently accurate information for comparative purposes. In order to overcome the differences caused by age when the measurements are made, the daily growth rate was calculated for each period, and this figure was the one used for comparison purposes and statistical analysis.

From the figures in Table 3, representing the results obtained from Romney 2-tooth ewes suckling twins in 1956, it is clear that there have been significant increases in the rate of growth of the lambs suckled by the thyroxine-treated ewes. It was possible in this experiment to obtain the birth weights of the lambs, and analysis of variance showed that the difference of 0.4 lb in favour of the controls was not statistically

TABLE 3. MEAN BIRTH WEIGHTS AND DAILY GROWTH RATES, 1956
(twin lambs suckled on Romney 2-tooth maiden ewes)

	No. of Lambs	Birth Weight lb	Daily Growth to Tailing lb	Daily Growth to Weaning lb
Control	16	8.6	0.56	0.49
Thyroxine 90 mg	14	8.2	0.78**	0.56*

** Sig. Diff. $P < 0.01$
* Sig. diff. $P < 0.05$

significant. On the other hand, the average weaning age difference of 13 days between the controls (98 days) and the treated (85 days), probably caused by a delay in conception induced by the thyroxine, was significant. In this connection it should be noted that, notwithstanding the 13-day difference, the treated lambs averaged 55.2 lb compared with the controls 56.0 lb at weaning, which was the same date for all lambs.

The 2-tooth ewes suckling single lambs results are shown in Table 4. Rather unexpectedly there is also a significant increase in the rate

TABLE 4. MEAN BIRTH WEIGHTS AND DAILY GROWTH RATES, 1956
(single lambs suckled on Romney 2-tooth maiden ewes)

	No. of Lambs	Birth Weight lb	Daily Growth to Tailing lb	Daily Growth to Weaning lb
Control	35	10.18	0.72	0.57
Thyroxine 90 mg	22	10.05	0.81**	0.62*

** Sig. diff. $P < 0.025$
* Sig. diff. $P < 0.05$

of growth of these single lambs from birth to weaning, although the difference is less than for the twins.

The mixed-aged ewes' results shown in Table 5 were very different from the 2-tooths, there being no significant difference in the rate of growth to or in the age of weaning between the two groups as was the case of the 2-tooths. The birth weights did however show a difference of 0.7 lb which was significant at the 10% level.

TABLE 5. MEAN BIRTH WEIGHTS, WEANING WEIGHTS AND DAILY GROWTH RATES, 1956
(twin lambs suckled on Romney mature ewes)

	No. of Lambs	Birth Weight lb	Weaning Weight lb	Daily Growth to Weaning lb
Control	24	10.2	61.96	0.56
Thyroxine 90 mg	42	9.5*	63.29	0.58

* Sig. diff. $P < 0.10$

The information from the 1956 experiments is interesting in that it shows that no response in lactation was obtained from the old ewes, whereas the young maiden ewes did respond to an autumn implantation of the same dose level as that used on the old ewes. This result is slightly at variance with that later obtained by Ross and Lewis (1958) who found no difference in daily growth rate between the thyroxine treated and control 2-tooth ewe lambs, but it should be noted that their

observations were not based on ewes suckling twins, as in this experiment, and could therefore not be expected to reveal differences unless they were potentially very substantial. This did not appear to be the case with their single Romney lambs.

1957 Experiments

These were carried out on a fat-lamb farm comprising two-thirds flats and one-third hill country within twenty-five miles of this College. The object was to determine whether the promising results obtained in 1955 and 1956 experiments could be reproduced on an ordinary commercial farm property.

The 2-tooth ewes only were implanted, on 20 February 1957. The dose was reduced to one pellet only of 30 mg, because indications of an adverse effect on the reproductive performance of 2-tooths subjected to the 90 mg dose within twenty-one days of being mated had been found (Ross and Lewis 1958).

The rams were run with ewes from 1 March and all the normal managerial treatment associated with that farm was given to both the implanted and control groups, which were treated as one mob throughout the period.

As it was not possible to tag individual ewes and lambs in this trial they had to be treated as two groups distinguished by paint marks on the ewes, similar marks being placed on the lambs as they were born.

As there was little or no difference in the date and rate at which the two groups lambed, and there was only 0.06 lb difference between the average weight of the two groups at tailing at 10 days old, it was decided that the weights used for measuring the milk production performance of the ewes should be the weights obtained when the lambs were drafted fat off the mother. It was necessary to adopt this procedure in order to reduce interference with normal farm management to a minimum; thus drafting date was synonymous with weaning date.

The first drafting of fat lambs off the mothers took place on 24 November 1947. This included a total of 67 lambs from the 2-tooth experimental and control groups; these lambs were all weighed immediately following drafting. The undrafted lambs were not weighed then but continued on their mothers until the final drafting of fat-off-the-mother lambs on 13 December 1957, when again only the lambs drafted as fat were weighed.

The results of the 1957 experiment are presented in Tables 6 and 7. As has been previously pointed out, this experiment was run under commercial fat-lamb farming conditions and as a result no birth-weights could be obtained. To some extent this defect was balanced by obtaining tailing weights at a reasonably early age, before the lambs were old enough to consume the ewes' full production and push them to their theoretical maximum level. These tailing weights show that there were no significant differences between the two groups at this time and it is extremely unlikely therefore that there were any significant differences in their birth weights.

TABLE 6. LIVE WEIGHT AT TAILING, 1957
(lambs suckled on 2-tooth maiden Romney ewes)

	Mean Date Weighing	No. of Lambs	Mean Live Weight lb	Diff.
Control	28 Aug.	97	18.3	+ 0.06 N.S.
Thyroxine 30 mg	29 Aug.	78	18.4	

TABLE 7. LIVE WEIGHT AT WEANING OF DRAFTED LAMBS ONLY, 1957
(lambs suckled on 2-tooth maiden Romney ewes)

	No. of Lambs	Percentage Drafted	Mean Live Weight lb	Diff.
Control	49 (includes 6 twins)	51	66.2	
Thyroxine 30 mg	41 (includes 8 twins)	53	68.5	+ 2.3**

** Sig. diff. $P < 0.01$

The data presented in Table 6 refer only to those lambs born early enough to be eligible for inclusion in the final groups from which the fats were drafted straight off their mothers, in late November-early December. It was necessary to adopt this procedure because without individually numbering each animal there was no other way of relating tailing weights to weaning weights. It must be recognised also that the lambs whose weights are recorded in Table 7 must, by the nature of the drafting procedure, represent a selected sample from each group which the fat-lamb buyer considered would not fall below a given weight. Interpretation of this result therefore is subject to the limitation that lambs below 55 lb live weight were not weaned and drafted.

From Table 7 it will be noted that the percentage drafted as fat, although slightly favouring the thyroxine group, does not differ greatly, and tends to preserve the equality of the balance of sample, between the groups that were finally used for measurement purposes. The main point is, of course, the difference in the weaning weight between the two groups which is 2.3 lb and highly significant (P 0.01%), despite the fact that the bias from a selected sample of this nature could be towards a masking effect, on any weight differences that might otherwise exist.

DISCUSSION

These three trials carried out during successive years have yielded some interesting results in many fields. The purpose of this paper is to present in as condensed a form as possible the effect of thyroxine implantation on lactation in ewes as measured by the growth rate of their lambs.

Differing combinations of dose rate, implantation date relative to lactation, and maiden versus mature ewes, have been tried for experimental purposes, and the resulting evidence suggests that thyroxine, as used in these experiments, can have some effect on the lactational performance of treated ewes.

The fact that both a pre- and post-lambing implant produced a lactation response in mature ewes whilst the autumn or tupping implant failed to do so is noteworthy. On the other hand, that autumn-tupping implant did appear to produce a response in maiden 2-tooth ewes, leads to considerable speculation as to the mode of action.

Conventional thought suggests that, as in the dairy cow, increased feed intake brought about by increased body metabolism, due to the effect of thyroxine on the animal, could be an explanation. As in all these experiments no attempt was made to measure the ewes' food intake, this first explanation cannot be disregarded and appears to be a likely one, especially as the work of Ferguson (1958) in connection with his critical studies on response of wool growth to thyroxine, suggests that this is in part due to an increased feed intake. Also, since the thyroxine-treated ewes lost weight relative to controls, there is the possibility of a re-distribution of this body tissue so as to become available for mammary tissue or milk production purposes. At the same time it must be recognised that the hormone-induced secretory phase of lactation could also have been influenced and so the resulting increases could be due to any one or combination of these factors operating.

Whilst these explanations may be suitable in accounting for the mature ewe response in that they merely depend on increased secretory activity or increased milk production due to the additional blood nutrients available, they may not be quite as satisfactory a method of explaining the apparent 2-tooth response occurring at a minimum period of five months following implantation.

It does not seem possible for the higher food intake hypothesis to operate as a means of increasing milk production so long after a single implantation, when all other known biological responses associated with administration of thyroxine, for example weight loss, wool growth (Hart 1955), appear to be no longer detectable. Therefore it seems probable that there may be some alternative approach towards the solution to this problem.

The possibility of the explanation being an endocrine one cannot be lightly discarded, especially if one accepts the principle of the hormonal control of mammary gland development in mammals, in which case it seems that the normal oestrogen-progesterone phases, characteristic of mammary tissue development and of particular importance in that associated with nulliparous females, could be being influenced in some way.

Mixner and Turner (1942) reported increased mammary growth from mice treated with thyroxine but the reports to date indicate some doubt as to whether the response is due to increases in duct or alveolar growth, or both. At the same time there is the suggestion of Weichert

and Boyd (1934) that feeding thyroxine increased mammary development as well as stimulating the secretory phase with pregnant rats.

It seems doubtful, however, that the secretory phase of the maiden 2-tooth ewes used in these experiments could have been affected by a thyroxine implant some five months earlier. Certainly there was no evidence of secretory phase increase in the performance of the mature ewes implanted prior to mating five months earlier.

It would seem therefore that the effect, if any, has been gained during the phase of intense mammary activity normally occurring in the maiden ewe during her first pregnancy, in which case there appear to be two possibilities: (a) that the treated animals have been consuming more food owing to the effects of the thyroxine and this has resulted in greater development of mammary tissues due to increased intake, or (b) the stimulation is purely of an endocrine nature, thyroxine having an influence on the oestrogen-progesterone balance of the animal in such a manner as to increase the effectiveness of the action of these two hormones in stimulating duct and alveolar growth and development in the mammary glands.

The first possibility seems rather doubtful as there is little or no evidence to support an effect on subsequent lactation resulting from animals forced to consume more of the same feed than controls which were on "ad lib." feeding, during the early stages of pregnancy. It seems therefore most unlikely that an artificially increased feed intake at an "ad lib." feeding level could, *per se*, be responsible for a subsequent lactation response. Nevertheless, because of the nature of these experiments and the inability to measure or control feed intake this possible explanation cannot be eliminated.

The second hypothesis of an endocrine stimulation, probably involving an interaction between oestrogen, progesterone, thyroxine, and possibly other hormones, appears to be worthy of consideration. However, at this stage it must be admitted that there is insufficient evidence bearing on the mode of the response available, to justify drawing any positive conclusions. All that can be said is that under certain circumstances a lactational response can be evoked in ewes by means of a thyroxine implantation.

One other interesting possibility which suggests itself is that if the improvement in 2-tooth maiden ewe lactation is due to increased duct-alveolar growth, as Mixner and Turner's (1942) work suggests, it could be that this may represent a more or less permanent increase of mammary secretory tissue whose production would be available in future lactations. Thus a thyroxine-treated 2-tooth might always tend to have a slight increase in milk production over an untreated one.

ACKNOWLEDGEMENTS

Thanks are due to the Nuffield Foundation for the financial support which has allowed these experiments to proceed; also to Glaxo Laboratories (N.Z.) and at Greenford (England) for the supply and manufacture of the thyroxine implant pellets used in the trials; to the

co-operative farmers who have allowed the use of valuable sheep for experimental purposes, and have assisted in the collection of data; and also to Mr. V. R. Clark and the farm staff at Ashley Dene for their assistance in recording.

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BLOOD CHEMISTRY AND HAEMATOLOGY IN SHEEP IN A SUDDEN DECREASE IN FOOD INTAKE

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(*Received for publication, 5 March 1959*)

Summary

Twelve dry, non-pregnant ewes were individually penned for 47 days and fed dried grass of uniform composition. After 19 days on 1000 g/day, the feed intakes were reduced overnight to 300 g/day for the remainder of the trial. Live weights at the end of the 1000 g/day period averaged 113 lb, and at the end of the 300 g/d period, 96 lb.

This sudden reduction in feed caused no significant change in blood sugar, keto acids, ketone bodies, amino acid nitrogen, non-protein nitrogen, inorganic phosphorus, serum calcium, serum magnesium, percentage neutrophils, percentage lymphocytes, haemoglobin, or haematocrit.

A slight rise occurred in total leucocytes.

Eosinophil levels indicated that the treatment caused no physiological stress.

Introduction

Earlier work (White *et al.* 1956) has shown the effect of successive decreases in feed intake on the blood picture of mature wethers. The ration was lowered in steps of 100 g/day from 1000 to 300 g/day over a period of 61 days, and the only substantial change in the constituents studied was in eosinophil levels. Only minor falls occurred in blood sugar, inorganic phosphorus, serum calcium, total leucocytes, haemoglobin, and haematocrit, while ketone bodies rose transiently.

It was not until these animals became very thin, and were completely starved that marked changes occurred, notably in blood sugar, phosphorus, ketone bodies, total leucocytes, eosinophils, and the neutrophil/lymphocyte ratio.

In former work, the animals were allowed time to adapt themselves to each decrease in intake, but body reserves had been greatly reduced when the 300 g/day level was imposed. Since the experiment was designed primarily to see what complications might be produced by inappetance it was thought desirable to know what was liable to happen to blood constituents when animals in good condition suffered a severe drop in feed intake. Another experiment was therefore designed, giving conditions as similar as possible to those previously imposed except that the feed intake was changed overnight from 1000 to 300 g/day.

Experimental

Twelve non-lactating, non-pregnant mature Romney ewes were individually penned for 47 days. Spring sheep pasture of uniform composition, consisting mainly of ryegrass, white clover, and paspalum, which had been dried for 30 minutes in a stream of air at 100–120°c, was fed in two equal amounts each day. Dry matter approximated 85%.

The initial feed level of 1000 g/day was maintained for 19 days and then reduced to 300 g/day for the remainder of the trial. Water was always available.

Live weights were measured at intervals of several days. All sheep were shorn three days before the start of the experiment. Three blood samples were collected at the 1000 g/day level, that is after 11, 13, and 19 days, and after 1, 3, 5, 8, 14, and 27 days on the 300 g/day level. Analytical methods were as used previously (White *et al.* 1956). The method for blood ketone bodies has since been published (Bakker and White 1957).

RESULTS

Weight Changes and General Condition of Animals

Average live weights are shown in Fig. 1.

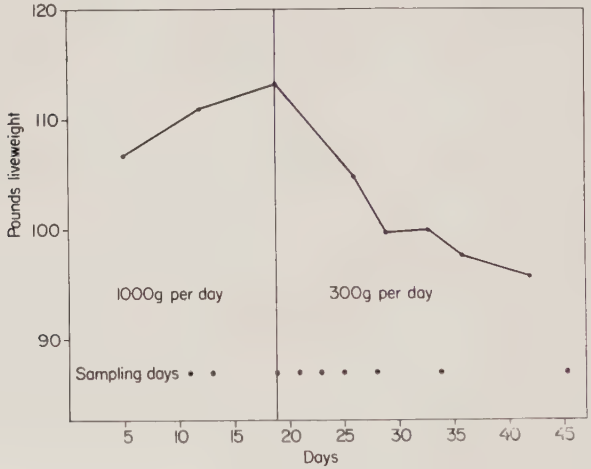

Fig. 1.—Average live weights.

Appetites were uniformly excellent and the animals gained an average of 6 lb during the last 15 days at the 1000 g/level to attain a freshly shorn live weight of 113 lb, when they were in good condition. Reduction of intakes to 300 g/day resulted in a loss of 13 lb over the next nine days, followed by a slower loss of 4 lb over the next 13 days. The animals were then hungry and thin, though not emaciated, with an average live weight of 96 lb.

Blood Findings

Biochemical and haematological data are shown in Tables 1 and 2.

It is apparent that there are no significant effects due to the decrease in feed intake on blood sugar, ketone bodies, keto acids, amino acid nitrogen, non-protein nitrogen (n.p.n.), inorganic phosphorus, serum calcium, serum magnesium, percentage neutrophils, percentage lymphocytes, haemoglobin, or haematocrit.

TABLE 1. Blood Chemical Constituents
(mg/100 ml)

Intake (g/day)	Sampling Day	Sugar Mean	Sugar s.d.	Ketone Bodies Mean	Ketone Bodies s.d.	Keto Acids Mean	Keto Acids s.d.	Amino-acid Nitrogen Mean	Amino-acid Nitrogen s.d.	Non-protein Nitrogen Mean	Non-protein Nitrogen s.d.	Inorganic Phosphorus Mean	Inorganic Phosphorus s.d.	Serum Calcium Mean	Serum Calcium s.d.	Serum Magnesium Mean	Serum Magnesium s.d.
	11	44	6	0.7	0.2	2.0	0.5	10.4	0.7	44	3	3.8	0 6	10.3	0.5	2.0	0 4
1000	13	45	5	1.4	0.3	1.7	0.5	9.7	1.0	43	4	4.3	0.6	10.8	0.5	2.1	0.3
19 days	19	41	6	1.8	0.4	1.6	0.3	10.7	0.5	41	3	4.8	0.8	10.1	1.0	2.2	0.3
	Av.	43	6	1.3	0.5	1.8	0.5	10.3	0.8	43	3	4.3	0.8	10.4	0.7	2.1	0.3
	21	42	5	1.9	0.2	2.2	0.4	8.1	0.6	40	3	4.9	0.6	10.0	0.4	2.1	0.2
	23	41	6	2.0	0.3	2.1	0.5	8.0	0.8	37	3	5.7	0.6	10.0	0.5	2.2	0.4
	25	48	7	2.0	0.4	2.2	0.3	9.1	0.6	40	3	4.8	0.4	10.2	0.5	2.3	0.5
300	28	42	4	2.1	0.6	1.9	0.2	8.9	0.5	38	4	5.0	0.5	9.7	0.7	2.0	0.3
27 days	36	41	4	2.3	0.6	1.3	0.2	9.2	0.5	39	2	4.3	0.6	9.9	0.5	1.9	0.3
	47	36	4	2.0	0.7	1.3	0.1	10.8	0.5	45	3	4.5	0.8	10.2	0.9	2.1	0 3
	Av.	42	5	2.1	0.5	1.8	0.3	9.0	0.6	40	3	4.8	0.6	10.0	0.6	2.1	0.5

TABLE 2. HAEMATOLOGICAL FINDINGS

Intake (g/day)	Sampling Day	Leucos $\times 10^3$ per cu. mm. Mean	s.d.	Neutros % of Leucos Mean	s.d.	Lymphos % of Leucos Mean	s.d.	Eosinos per mm^3 Mean	s.d.	Haemoglobin g/100 ml Mean	s.d.	Haematocrit R.B.C. Vol. % Mean	s.d.
1000 19 days	11	7.6	1.9	22	8	66	11	620	240	14.8	2.1	41	6
	13	7.7	1.4	23	7	62	7	860	330	14.8	1.8	41	6
	19	7.3	1.8	16	6	68	8	930	400	14.7	1.6	41	5
	Av.	7.5	1.7	20	8	65	9	800	350	14.8	1.8	41	5
300 27 days	21	8.4	1.9	16	7	64	9	1050	450	15.4	1.7	42	5
	23	8.5	—	19	9	61	5	—	—	14.9	1.8	44	5
	25	9.3	2.3	16	7	64	8	1280	490	14.4	1.8	41	5
	28	8.9	1.9	16	6	64	10	1090	440	14.6	1.1	43	5
	34	9.7	2.3	17	4	59	11	1140	320	14.2	1.6	41	5
	47	7.7	1.8	—	–	—	—	900	550	14.6	1.6	45	6
	Av.	8.8	—	17	7	62	9	1090	450	14.7	1.6	44	5

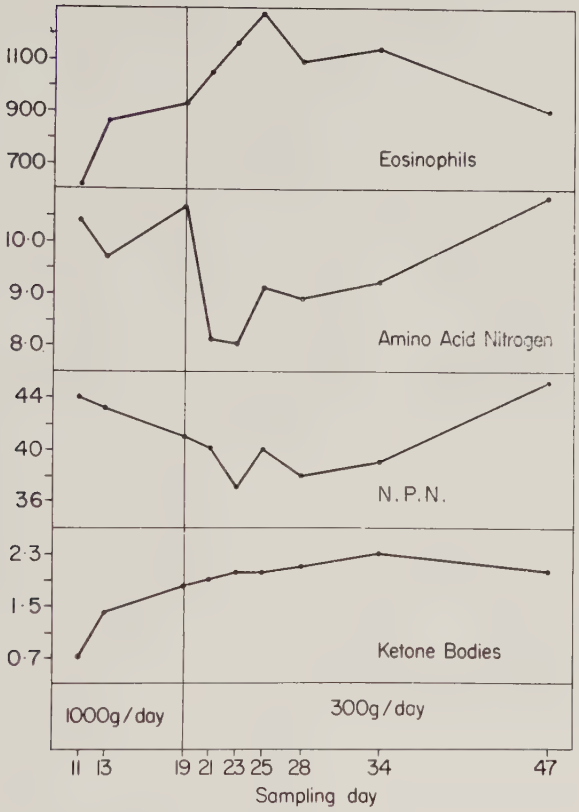

Fig. 2.—Effect on blood constituents.

Statistical analysis shows that the slight rises in total leucocytes and eosinophils are significant.

Plots of ketone bodies, amino acid nitrogen, n.p.n. and eosinophils show interesting trends and they are presented in Fig. 2.

DISCUSSION

The changes in blood constituents found in this trial were all small, the values remaining within the limits of reported normality. However, trends in such data can be of importance.

Eosinophil levels are indicators of stress reactions (Dalton and Selye 1939). The plot in Fig. 2 shows a rising eosinophil level during the 1000 g period followed by little change when feed intake was lowered. The sheep were probably adapting themselves to being shorn during the early stages of the 1000 g period and the change in feed intake apparently caused little physiological stress.

The trend in amino acid nitrogen (Fig. 2) would indicate an immediate increase in the rate of amino acid utilisation with a fall in

feed intake, with a gradual adaptation, allowing blood levels to return to normal. This is interesting as amino nitrogen did not change during the previous trial when the more mobile nitrogen reserves of the body had been depleted (White *et al.* 1956).

The falling n.p.n. level on the higher feed intake (Fig. 2) cannot be readily explained as an adaptation to this diet. After the feed was decreased, n.p.n. and amino acid nitrogen showed similar trends, which is probably a true inter-relationship.

The higher body reserves available to the animals in this experiment appear to have overcome the tendency towards hypoglycaemia and upsets in ionic balance. It is surprising that the rapid mobilisation of fat for energy, which is likely to have occurred, produced no greater increase in ketone bodies, and it must be assumed that the oxidation mechanism was not overloaded and was accompanied by adequate carbohydrate utilisation. The rise which took place in ketone bodies on the higher feed level (Fig. 2) could result from a number of adaptations, for example the gradual increase in the supply of butyric acid from the rumen.

These changes in eosinophils, amino acid nitrogen, n.p.n. and ketone bodies on the 1000 g level could represent normal variations and the fact that a trend was present in the data could be fortuitous. Samples taken at this level may have been too few.

The evidence suggests that mature, non-pregnant, non-lactating animals must undergo a very severe fall in intake before the regulatory mechanisms become unable to cope adequately with catabolic processes. That complete starvation of such animals may lead to important changes in serum calcium and magnesium will be described later, and no doubt levels of other constituents would be greatly affected. However, it may be assumed where moderate reductions of intake in pregnant, lactating, growing or diseased animals produce different results from those obtained here that the changes are peculiar to the physiological or pathological condition of the subject.

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THE INFLUENCE OF GROWTH HORMONE ON GROWTH IN YOUNG CATTLE

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(*Received for publication, 1 April 1959*)

Summary

Twelve pairs of identical-twin heifer calves were divided into 3 groups. For 12 consecutive weeks daily injections were carried out as follows:

Group 1	Growth hormone	5 mg/100 lb body weight
Group 2	L-thyroxine	0.5 mg/100 lb body weight
Group 3	Normal saline	1 cm^3

During the injection period the growth-hormone group gained in live weight by approximately 14 lb more than the control group, whereas the weight gain of the l-thyroxine group was some 12 lb less than that of the control group.

The extra gain in height made by the growth hormone and l-thyroxine groups compared with that made by the control group amounted to 20 mm and 14 mm respectively.

L-thyroxine increased blood-sugar levels by some 20–30%. The increase in blood sugar recorded in the growth-hormone group was slightly less than this and was probably due to the contamination of the growth hormone with thyrotrophic hormone. Non-protein nitrogen levels in the blood were unaffected by either growth hormone or l-thyroxine.

Introduction

The fact that the anterior lobe of the pituitary gland provides a key mechanism in the control of growth was recognised many years ago. More recently a hormone of reasonable purity, termed growth hormone, was isolated from the anterior pituitary of cattle. (For reviews see Ketterer *et al.* 1957). To some extent at least the name growth hormone is something of a misnomer, for compared with its manifold physiological effects its influence on growth is relatively limited. Clarification of the manifestations of growth hormone in experimental animals is complicated by the species specificity of this substance, together with the species-dependent response elicited by currently available growth-hormone preparations. To add further to the confusion many of the growth-hormone preparations in use contain sufficient quantities of other pituitary hormones to confound the interpretation of experimental results.

In recent years a number of attempts have been made to associate growth rates in farm animals with secretion rates of growth hormone. Thus Baird *et al.* (1952) found greater amounts of growth hormone in the pituitaries of rapidly growing pigs than in contemporary animals with a lower growth rate. More recently Armstrong and Hansel (1956) reported a positive correlation between the rate of growth of Friesian heifers and the growth hormone content per gramme of anterior pituitary, also between growth rate and the thyrotrophic hormone content of the pituitaries. However, bearing in mind the formidable technical diffi-

culties of the assay of growth hormone and of the interpretation of the assay when other pituitary hormones are present it remains a moot point whether the variations in the growth rate of normal intact animals are actually associated with variations in their growth-hormone status.

In view of these attempts to correlate growth rates with endogenous output of growth hormone, it was considered desirable to measure the effect of this hormone on the rate of live-weight gain of young healthy calves.

EXPERIMENTAL

Twelve sets of identical-twin Jersey heifers approximately 12 weeks of age were split into three groups of eight animals to form replicated

TABLE 1. SET NO. AND TREATMENT

Growth Hormone	Thyroxine	Control	Date Birth
36	35		25/7
56	55		28/7
33	34*		14/7
42	41*		20/7
48		47	25/7
50		49	14/7
58		57	27/7
85		86	23/7
	32	31	8/7
	37	38	19/7
	52	51	24/7
	53	54	27/7

Injections started 9/11
Injections stopped 1/2
Animals weaned 28/12

Calf 34—Broke a foot 20/11
Calf 41—Died 20/12 (Hypomagnesemia?)
} Data analysed excluding these two sets.

incomplete randomised blocks (Table 1). Each of the three groups were then assigned at random to one of three treatments, viz.

1. Growth hormone
2. L-thyroxine
3. Control

Growth hormone was administered as a subcutaneous injection at the rate of 5 mg/100 lb body weight. It was known that the growth hormone used (Armour batch No. R527094B) contained approximately $1\frac{1}{2}$ units of thyrotrophic hormone (T.S.H.) (U.S.P. Standard) to each 5 mg of growth hormone. As supplies of T.S.H. were not available at the time l-thyroxine was used in its place at a dosage designed to approximate $1\frac{1}{2}$ T.S.H. units per 100 lb body weight, i.e. 0.5 mg l-thyroxine for each 100 lb of body weight. The third group provided the controls which were injected with 1 cm^3 of normal saline daily. Injections continued on a daily basis for 12 weeks.

Prior to weaning, seven weeks after the start of the trial, all animals were fed 8 pints of skim milk and 2 lb of a mixed meal ration daily and were given unlimited access to good quality grass. Following weaning, the meal ration was increased to 3 lb daily plus grass *ad lib.*

Body weights and height at withers were recorded each week and in the latter part of the experiment the blood glucose and non-protein nitrogen fractions of the blood were estimated by the methods commonly used in this laboratory (Brumby and Hancock 1955).

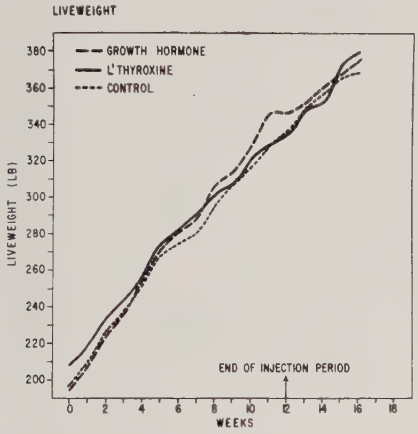

Fig. 1

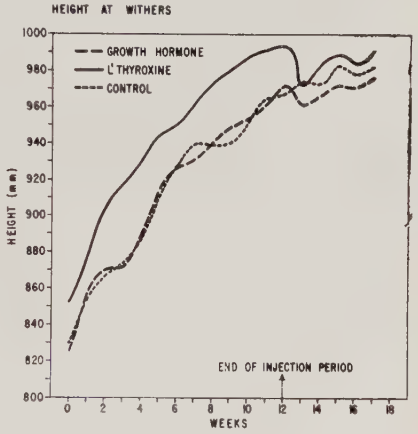

Fig. 2

Fig. 1.—Average weekly body weight.

Fig. 2.—Average weekly height at withers.

RESULTS

The average weekly body weight and height at withers for each group for the 12 weeks of daily injections and those for the following five weeks are illustrated in Figs. 1 and 2. The removal of two sets of twins from the experiment (see Table 1) resulted in a discrepancy as between treatments in starting weight and height which complicated the interpretation of results. To overcome this difficulty, group means were adjusted by the method of fitting constants (Tables 2 and 3). The differences in weight gain among the three groups were also computed from weeks 0 to 12, 0 to 17, and 12 to 17. These differences were then subjected to an analysis of variance (Tables 2 and 3).

Analyses of the body weights of the three groups at the end of 12 weeks of injections indicated that a significant treatment effect had been established. The standard error of the group means was of the order of $3\frac{1}{2}$ lb and the difference required for significance between any two of the three treatments (P 0.05) was approximately four times this (Snedecor 1956 Table of Q values), thus the increment of 14 lb made by the growth-hormone group over and above the weight gain of 139 lb made by the control group approximated the difference required for significance at $P = 0.05$. L-thyroxine had quite the opposite effect on live-weight gain

TABLE 2. ANALYSIS OF LIVE-WEIGHT DATA

Source of Variation	d.f.	0 weeks	12 weeks	17 weeks	12–0 weeks	17–0 weeks	17–12 weeks
		M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Between sets	9	681.339**	1115.050**	1008.561**	253.9	276.0	215.5
Within sets	10	6.050	288.350	204.750	289.3	172.7	114.3
Treatment	2	1.063	1064.565**	237.500	1102.5**	266.07	299.57**
Error	8	7.297	92.43	196.563	86.0	149.36	67.98

Means (lb)	Act.	Adj.	Act.	Adj.	Act.	Adj.	Act.	Act.	Act.
Growth hormone	194.3	199.4	347.8	354.5	359.3	365.5	153.5	165.0	11.5
L-thyroxine	208.7	200.2	355.8	322.3	363.7	350.5	127.2	155.0	27.8
Control	196.9	199.3	336.1	341.9	354.9	360.5	139.3	158.0	18.8

TABLE 3. ANALYSIS OF HEIGHT DATA

Source of Variation	d.f.	0 weeks	12 weeks	17 weeks	12–0 weeks	17–0 weeks	17–12 weeks
		M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Between sets	9	2984.03	2722.36	1370.14**	935.6*	1675.0	1996.7
Within sets	10	1333.75	2376.25	216.25	440.0	1105.0	2147.5
Treatment	2	1101.17	4514.07	178.13	1235.6*	588.6	3529.7
Error	8	1391.90	1841.80	225.78	241.1	1234.1	1802.0

Means (mm)	Act.	Adj.	Act.	Adj.	Act.	Adj.	Act.	Act.	Act.
Growth hormone	826.7	846.8	973.3	988.5	976.7	990.8	146.7	150.0	3.33
L-thyroxine	853.3	841.2	994.2	989.7	991.7	980.8	140.8	138.3	−2.50
Control	830.6	820.8	957.2	941.6	983.1	979.6	126.9	152.5	25.63

for the body-weight gain of these calves was some 12 lb less than that made by the control group. Following the cessation of daily injections the live-weight gain of the l-thyroxine group appeared to be accelerated whereas that of the growth-hormone group remained relatively constant. Analysis of the live-weight gain from the 12th to the 17th week for each group confirmed that the difference in gain between the growth hormone and l-thyroxine group during this period was significant. Final between-group differences in body weight 17 weeks after the start of injections were small and not significant.

Analysis of the absolute height data failed to reveal significant treatment differences, whereas analysis of the gain in height during the 12-week injection period showed a significant difference between groups. The standard error of the mean gain in height was approximately 5 mm,

thus the 20 mm difference in height gain between the growth hormone and control group was just significant; the extra 14 mm gain made by the l-thyroxine group compared with the control group was not significant. Following the cessation of injections the height gain of the growth hormone and l-thyroxine groups appeared to be reduced; an analysis of variance indicated that the between-group differences for the 12th to 17th weeks were not significant. As was the case with liveweight, the overall effect of the two hormones on height was negligible.

TABLE 4. ANALYSIS OF BLOOD GLUCOSE DATA

Source of Variation	d.f.	10 weeks	12 weeks	14 weeks
		M.S.	M.S.	M.S.
Between sets	9	57.880	41.672**	80.583
Within sets	10	104.700	35.550	47.250
Treatment	2	408.500**	155.065**	43.170
Error	8	28.750	5.671	48.270

Means	Actual		Actual		Actual	
Growth hormone	64.7	62.8	62.2	61.9	46.0	46.5
L-thyroxine	75.0	74.8	66.3	65.1	44.7	45.9
Control	57.8	57.3	55.3	55.0	51.4	50.8

TABLE 5. ANALYSIS OF BLOOD N.P.N. DATA

Source of Variation	d.f.	10 weeks	12 weeks	14 weeks
		M.S.	M.S.	M.S.
Between sets	9	9.429*	11.075	10.178
Within sets	10	3.044	4.537	9.670
Treatment	2	6.441	2.432	11.284
Error	8	2.195	5.063	9.267

Means*	Actual	Actual	Actual
Growth hormone	32.7	30.3	37.9
L-thyroxine	32.9	32.3	36.9
Control	34.3	31.2	35.4

* As the treatment effect was non-significant throughout, means were not adjusted.

The influence of the growth-hormone preparation on blood-sugar levels was quite marked (Table 4, Fig. 3); even so, its effect was less than that of the l-thyroxine which caused an increase of some 14 mg %. No carryover effects were apparent. The influence of both hormone preparations on the non-protein nitrogen level of blood appeared negligible (Table 5, Fig. 4).

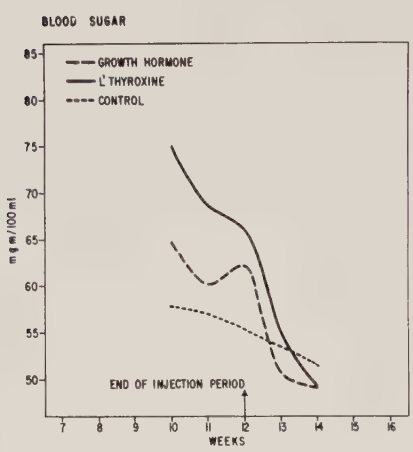

Fig. 3

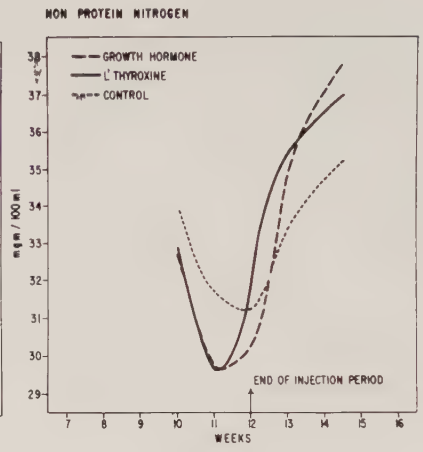

Fig. 4

Fig. 3.—Effect on level of blood sugar.

Fig. 4.—Effect on level of non-protein nitrogen.

DISCUSSION

The end result of 12 weeks of daily growth-hormone injections to fully fed young calves was an increase in body weight of some 14 lb over their identical-twin mates. This small difference in weight proved to be quite transitory, since five weeks after the end of the injection period this difference had largely disappeared. As indicated by the l-thyroxine group the effect of the growth hormone on live-weight gain was probably diminished by its contamination with T.S.H. (assuming no synergism between the two hormones), for the l-thyroxine group made a somewhat slower live-weight gain than the control group. On the other hand l-thyroxine tended to increase height at withers, as was the case in a former experiment (Hancock *et al.* 1955). In consequence it seems likely that the apparent effect of the growth hormone preparation on height may be accounted for in terms of its T.S.H. content. Similarly the effect of l-thyroxine on blood sugar is such as to account for the so-called diabetogenic effect of growth hormone in cattle. This conclusion together with the absence of any clear effect of growth hormone on the n.p.n. content of blood are in agreement with the results obtained by injecting growth hormone into lactating cattle (Brumby and Hancock 1955).

The small and transitory effect of bovine growth hormone upon the growth of young cattle suggests that simple quantitative differences in the secretion of growth hormone in different cattle are insufficient to account for the variation in growth rates observed amongst a group of uniformly treated animals. Moreover, the uniform response of each animal to the hormone treatment, with the consequent lack of set and treatment interactions implies that little variation exists between animals in the use made of available levels of circulating growth hormone.

ACKNOWLEDGEMENTS

I am indebted to Armour laboratories, through the courtesy of Dr. I. Bunding, for supplying the growth-hormone preparation; to Miss M. Williams, who undertook the care of the calves: to Miss L. Notman, who performed most of the statistical computations; to Dr. A. H. Carter for his comments on statistical method; and to Mr. R. R. White, who carried out the blood sugar and n.p.n. estimations.

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A VOLUMETRIC SPORE TRAP FOR SAMPLING PASTURES

By P. J. BROOK, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

(*Received for publication, 22 April 1959*)

INTRODUCTION

When it was established that the fungus *Sporidesmium bakeri* Syd. can cause the disease of sheep known as facial eczema (Thornton and Percival 1959), the need arose for a method of estimating the amount of this fungus in a pasture. The rapid sporulation of *S. bakeri* and the

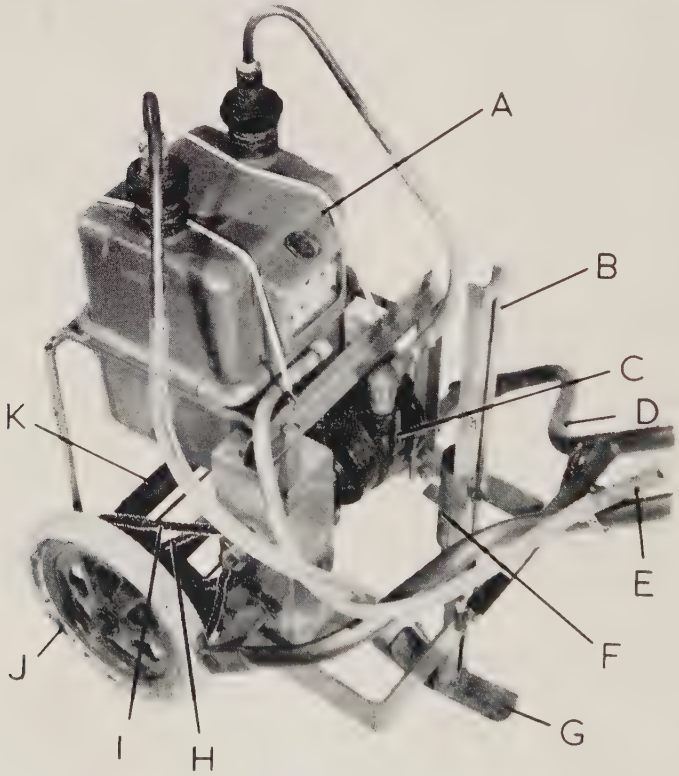

Fig. 1.—A general view of the spore trap showing:

A. gas meter
B. track mounting for impactor
C. sliding-vane pump
D. lawn-mower handle
E. exhaust tube
F. impactor
G. skid
H. beater drive chain
I. pump drive chain
J. wheel (8½ in. diameter)
K. beater (9 in. wide)

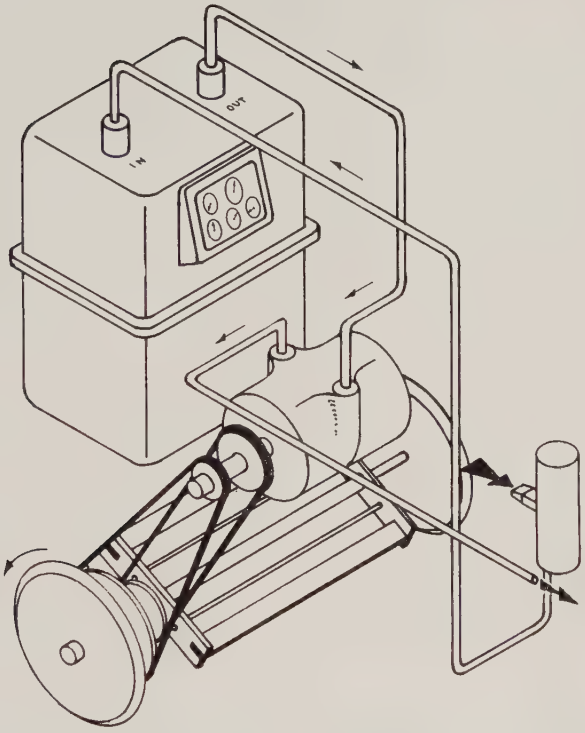

Fig. 2.—Flow diagram of spore trap, giving relationship of parts shown in Fig. 1. Arrows show path of air from impactor to exhaust.

ease with which the conidia are detached suggested that assessment of spore numbers should give a fair measure of the abundance of the fungus.

A machine to sample spore populations has therefore been designed (Fig. 1). It is essentially a volumetric spore trap mounted on wheels for pushing over the pasture, sampling being carried out while the trap is moving. Rotating blades between the wheels, in front of the impactor orifice, throw up spores from the pasture, and the spores are sucked into the impactor by a sliding-vane pump driven off the wheels. The vertical position of the impactor is adjustable. A domestic model gas meter in the line between the pump and the impactor measures the air taken through the impactor, and also smooths the flow. The spore trap is based on the portable volumetric spore trap designed by Gregory (1954), and has an identical impactor unit using sticky microscope slides prepared in the same way. In other respects, however, the spore trap differs from Gregory's instrument. A flow diagram of the machine is given in Fig. 2.

OPERATION

For sampling aerosols with an impactor of the type used here, May (1945) emphasised the importance of the flow rate through the orifice, and recommended isokinetic sampling. In the present case a rather arbitrary approach has been made to this problem since the air sampled is in a turbulent state, being partially enclosed by the machine while it is disturbed by the rotating blades. By putting a constriction in the air-line, the flow rate was therefore adjusted to approximately 0.6 ft^3/min (17 l/min), when the machine is travelling at 2.5 m.p.h. (a comfortable working speed). With the impactor orifice 9 inches above ground level, a total sample of 2 ft^3 gives a useful deposit on the slide. To pump 2 ft^3 of air, the machine travels about 250 yards.

APPLICATION

This spore trap has been designed primarily to collect spores of *S. bakeri* from pastures, and it enables relative measurement to be made of the amounts of that fungus present in different areas. The advantage of the machine is that spores from a comparatively large strip of pasture are concentrated on to a small area of a microscope slide for rapid examination.

Part of a slide sample taken from a pasture is shown in Fig. 3. Since conidia of *S. bakeri* are large and easily recognised they can be counted rapidly.

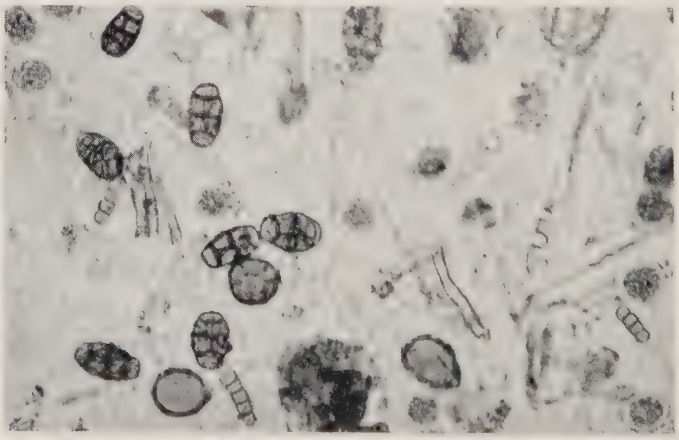

Fig. 3.—Conidia of *Sporidesmium bakeri* (the dark, barrel-shaped dictyospores), on a slide taken from an Auckland pasture (× 400).

ACKNOWLEDGEMENT

I wish to thank Mr. A. J. Yates for his assistance with the final design of the spore trap, and the Auckland Industrial Development Laboratories for building the prototype machine.

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THE ORIGIN OF CAROTENOIDS, VITAMIN A, AND TOCOPHEROL IN COLOSTRUM

By W. A. McGillivray, Massey Agricultural College, Palmerston North

(*Received for publication, 31 March 1959*)

Summary

The changes in quantity of carotenoids, vitamin A, tocopherol, and proteins in the blood plasma of cows near parturition have been further investigated. The cows were pasture-fed but in some cases their carotene and tocopherol intakes had been depressed by drenching with heavy liquid paraffin prior to calving.

Close quantitative relationships have been established between decreases in carotene, vitamin A alcohol, and tocopherol in the plasma and the amounts of these substances secreted by the mammary gland at the onset of lactation.

It is suggested that, at the start of lactation, these substances are taken up by the mammary gland along with the proteins with which they are associated in the blood plasma and that the increased quantities of these substances in the colostrum result merely from the increased uptake of plasma proteins at that time.

The proteins involved appear to be globulins and are associated with the globulin fraction of colostrum.

Introduction

The dosing of cows with various oils, either by drenching or by spraying the pasture, has been found effective as a prophylactic against bloat. Recently attention has been focussed on the use of heavy liquid paraffin, which is one of the least expensive oils found suitable for this purpose (Reid 1957), and effects of using this oil have been under investigation for some time (McDowall *et al.* 1957; McGillivray 1957a; McGillivray and Worker 1958; McGillivray *et al.* 1959).

These studies are of interest from the point of view of the health and milk production of the animals and the composition and nutritive value of their milk. However, in addition to this, dosing with heavy liquid paraffin provides a very convenient method of limiting the fat-soluble-vitamin intake of pasture-fed cows, and, as a result, the most recent investigation afforded the present author an opportunity to extend previous investigations into the origin of various milk constituents. With this in view, a large number of assays were carried out in this laboratory on the fat-soluble-vitamin content of the blood and early milk of paraffin-treated and control cows. For convenience, these results, together with details of the heavy-liquid-paraffin drenching, have all been reported in the previous paper (McGillivray *et al.* 1959). These experimental details and results are not therefore repeated here although use is made of much of the data from the previous communication.

Changes in the vitamin A and carotenoid contents of blood plasma near parturition have already been studied under New Zealand condi-

tions by Thompson and McGillivray (1957). Confirming and extending the observations of earlier workers in Great Britain (Walker *et al.* 1949; Goodwin and Wilson 1951) and in the United States (Sutton and Soldner 1943; Kuhlman and Gallup 1944; Sutton *et al.* 1945; Braun 1945), Thompson and McGillivray found marked decreases in the carotenoid and vitamin A levels in the blood plasma despite the high carotene intake of the pasture-fed cows. Largely on the basis of differences in the blood plasma picture between cows and heifers, these workers concluded, contrary to the suggestion of Goodwin and Wilson (1951), that the drop in plasma levels is due to the abnormally large uptake of carotenoids and vitamin A by the mammary gland at the onset of lactation, rather than to any physiological disturbances directly associated with parturition. If this is the case, fairly direct relationships would be expected between the quantities of these constituents secreted in the colostrum and the magnitude of the decreases in the blood at parturition. Furthermore, from other evidence, it has been suggested (McGillivray 1957b) that these carotenoids and vitamin A are taken up by the mammary gland in association with blood plasma proteins, probably globulins. Thus the increased quantities of carotenoids and vitamin A in the colostrum should bear a relationship to the amount of globulin secreted. Tocopherol secretion was also investigated since it might be expected that its appearance in the blood and uptake by the mammary gland would be similar to that of the carotenoids and vitamin A.

Experimental

The groups of cows, their experimental treatments, the collection of milk and blood samples and the assay methods were all as already described (McGillivray *et al.* 1959).

In addition, milk proteins were fractionated and determined as described by Rowland (1938). Iodine values and Reichert values were determined by the British Standard Method (1938).

Total proteins were also determined in pooled blood plasma samples from nine cows by the Kjeldahl method.

Results

Levels of Carotenoids, Vitamin A, and Tocopherol in Blood and Milk

These have already been reported (McGillivray *et al.* 1959).

Level of Proteins in Blood Plasma

Up to about ten days before parturition the average total protein content of the blood of the nine cows varied from 7.5 to 8.0% with indications of a slight rise in level over the period 17 to 10 days prior to parturition. During the ten days immediately before parturition the protein content of the blood decreased steadily to a minimum level at parturition of 5.9%. During the five days following parturition the blood protein content returned to normal and thereafter fluctuated between 7.6 and 8.0%.

Milk Proteins and Fat Constants

Average total protein, casein, globulin, and albumin contents of the milk of the nine cows are shown in Fig. 1. Average iodine values and Reichert values of the milk fat are also included in the same figure. It is of interest to note that although the percentage of each of the protein fractions decreased from the onset of lactation, increasing milk yield resulted in a fairly uniform total-protein secretion over the period covered. As shown in Fig. 2, there was, however, the anticipated sharp decrease in the daily secretion of globulins together with a smaller decrease in albumins.

Iodine values decreased over the period covered and Reichert values showed a corresponding increase.

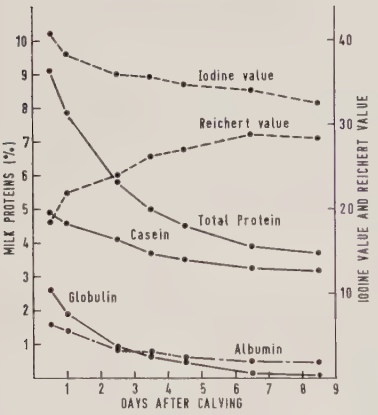

Fig. 1

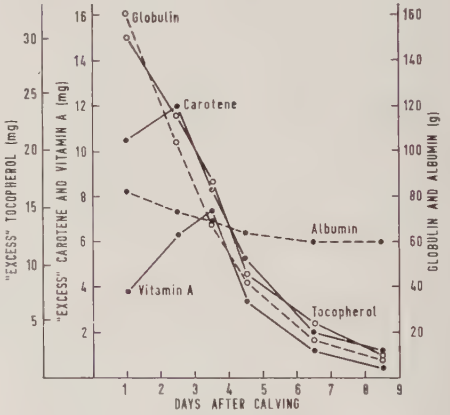

Fig. 2

Fig. 1.—Average total proteins, casein, globulin and albumin levels in the colostrum and early milk, and iodine values and Reichert values of the milk fat of nine cows.

Fig. 2.—Average daily globulin and albumin secretions and average daily "excess" carotene, vitamin A and tocopherol secretions of nine cows.

Discussion

As has already been discussed by Thompson and McGillivray (1957) for carotenoids and vitamin A, and has been advanced as a partial explanation by Parrish (1949) for tocopherol, an abnormally large uptake by the mammary gland of blood constituents at the onset of lactation could result in the decreases observed near parturition in blood carotenoids, vitamin A alcohol, and tocopherol. It is more difficult to explain the pre-parturition increases in blood carotenoids and tocopherol observed both in this investigation and previously with pasture-fed cows (Thompson and McGillivray 1957). The general upward trend in levels after calving is, however, significant, blood carotene, xanthophyll, and tocopherol being considerably higher at the end than at the start of the period covered in the present investigation.

Thus it may be that the pre-parturition increases represent merely the start of seasonal increases in those blood components which are, to some extent at least, of immediate dietary origin. Changing composition of the pasture or environmental factors could initiate these blood increases which are then interrupted by parturition.

It is significant that other blood constituents in which decreases have been reported near parturition such as lipids, calcium, and phosphorus (Niedermeiler *et al.* 1949), and plasma proteins (Larson and Kendall 1957), are also all secreted in large quantities in the colostrum. Larson and Kendall have in fact shown that the drop in blood-plasma proteins corresponded to the time colostrum was being formed in the mammary gland and on the basis of practical considerations and similarities in electrophoretic patterns, conclude that the immune globulins appearing in the colostrum are identical with those leaving the bloodstream.

It is well recognised that blood contains protein-bound forms of carotenoids and vitamin A (e.g. review by Deuel 1955). Similar protein-bound forms of carotene, xanthophyll, and vitamin A alcohol have been found in mammary secretions by McGillivray (1957b) who has pointed out that, although under normal conditions the bulk of the carotenoids and vitamin A in milk is derived through the uptake by the mammary gland of chylomicrons containing vitamin A ester and carotenoids of immediate dietary origin, increased levels of carotenoids and vitamin A which occur, for example, at the onset of lactation or in mastitis milk, are always associated with elevated milk-protein levels. On the basis of this and other evidence he therefore advanced the suggestions that the protein or proteins with which carotenoids and vitamin A alcohol are associated in the blood may, under these circumstances, pass into the colostrum or milk without modification by the mammary gland; that during the changes which occur in the cells of the mammary gland much of these protein-bound carotenoids and vitamin A alcohol becomes dissociated from the proteins and is transferred to fat, the vitamin A alcohol being fairly completely esterified in the process; and that an increased uptake of protein-bound material by the mammary gland is responsible for the high levels of carotenoids and vitamin A found particularly at the onset of lactation.

Precise information regarding the particular protein or proteins concerned is lacking, but there is strong evidence to suggest that components of the globulin fraction are involved. Larson and Kendall (1957) showed the loss from the blood and appearance in the colostrum of specific globulins at the onset of lactation. McGillivray (1957b) found some carotenoids and vitamin A alcohol in the casein, albumin, and globulin fractions of milk, with the highest concentration in every case in the globulin fraction. Both globulins and albumins have been suggested as the proteins linked to carotenoids and vitamin A in blood, but, in the case of carotene at least, the main weight of evidence again favours a globulin (Deuel 1955).

On the assumption that the proteins involved are globulins and that carotenoids and vitamin A alcohol are taken up by the mammary gland

in association with these proteins, relationships were investigated between the quantity of globulins and the "excess" carotenoids and vitamin A secreted during the first few days of lactation, and between these "excess" secretions and the quantities of carotenoids and vitamin A alcohol lost from the blood near parturition. In this latter comparison, data from the present investigation were extremely useful because of the abnormally wide range of plasma levels of carotene and tocopherol resulting from the experimental treatment. Use was also made of values calculated from the experimental data which formed the basis of a previous communication (Thompson and McGillivray 1957) relating to blood levels of carotenoids and vitamin A for cows and heifers near parturition and also of figures calculated from similar results which were available from one other cow, i.e. 20 cows and heifers in all. In these comparisons the term "excess" is used to imply carotenoids and vitamin A in the colostrum over and above normal levels secreted. It is calculated by subtracting from the level present in each colostrum sample (expressed as μg/g fat) the normal level attained some 10–14 days after calving (also expressed in μg/g fat) and multiplying the difference by the weight of fat secreted at that particular milking. Thus, to take a particular case, on the first day of lactation one animal secreted 285 g fat containing 53 μg carotene per gramme. Ten to fourteen days after calving the level of carotene in the fat had fallen to 9.2 μg. The "excess" carotene on the first day of lactation, due, it is assumed, to an uptake of protein-bound carotene from the blood, is (53–9.2) $\times$ 285 μg, or 12.5 mg.

It is not possible to determine precisely the quantities of the various constituents lost from the blood where the level present at any time merely represents the equilibrium between rate of removal of a constituent and rate of replacement from body reserves or dietary sources. Furthermore, although all animals showed similar trends in blood levels near parturition, there were a number of individual differences affecting the shape of the curves, particularly the rate at which levels decreased and increased, and the time at which the minimum level was recorded. (This usually occurred on the day of calving or one day before or after calving.) From a consideration of the individual curves it seemed that the most reliable comparison of blood decreases would be obtained by subtracting from the pre-parturition maximum the mean of the two lowest values recorded. An indication of the quantity of each constituent lost from the blood was then obtained on the basis that, in the bovine, blood constitutes about 7.7% of the body weight (Dukes 1947) and contains 50% plasma. The actual quantities lost from the blood would be greater than suggested by this calculation, but, assuming that the rate of replacement of blood constituents is similar for all the cows, the values obtained all represent the same proportion of the true losses.

For milk constituents, secretion on the first six milkings after calving was considered. The choice of this period is somewhat arbitrary but it did correspond in most cases to the time of low blood-plasma levels. The "excess" vitamin A secretion figures used take into account both the alcohol and ester forms.

Tocopherol relationships were also investigated in a similar manner.

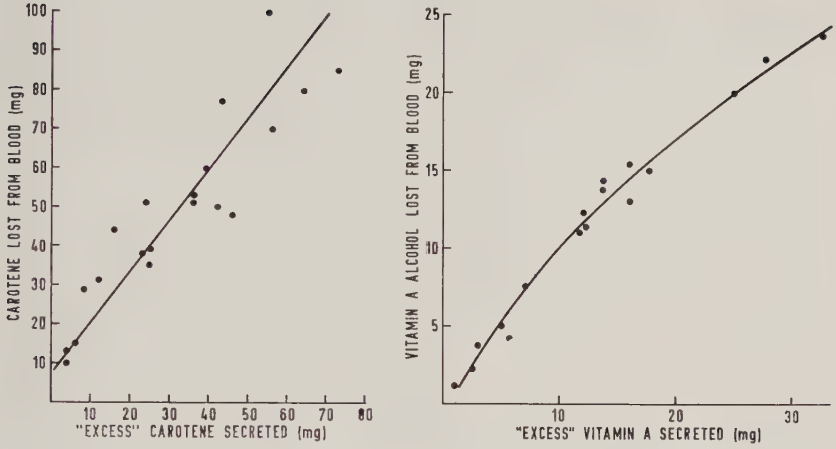
CAROTENE LOST FROM BLOOD (mg)
"EXCESS" CAROTENE SECRETED (mg)
VITAMIN A ALCOHOL LOST FROM BLOOD (mg)
"EXCESS" VITAMIN A SECRETED (mg)

Fig. 3.—Relationships between carotene and vitamin A alcohol lost from the blood near parturition and "excess" secretion of these substances in the colostrum over the first six milkings. Carotene data showed no significant departure from linearity, the fitted regression line being $M = -5.49 + 0.76\ B$ with a standard error from this line of $\pm$ 8.7. In the case of vitamin A there was significant curvilinearity in the data, the fitted quadratic regression curve being $M = +1.02 + 0.59\ B + 0.03\ B^2$ with standard error of $\pm$ 1.1. (M + B represent the "excess" milk levels and the loss from the blood of carotene and vitamin A respectively.)

From Fig. 3 it is apparent that very close correlations exist between "excess" colostral secretions of carotene and vitamin A and the quantities of these substances lost from the blood. Simple correlation coefficients were + 0.911 and + 0.982 for carotene and vitamin A respectively. Only 17 animals are included for vitamin A since the other three showed abnormal pre-parturition blood-plasma fluctuations which prevented any assessment of the real magnitude of the parturition decreases. It will be apparent in some cases that the "excess" vitamin A secretion was greater than the blood losses shown but as already pointed out true blood losses would be higher than those indicated in Fig. 3. A similar correlation (+0.954) was established between blood losses and "excess" secretions of tocopherol for the 9 cows where this vitamin was determined. The average daily secretion of globulins and albumins and the average "excess" secretions of carotene, vitamin A, and tocopherol are shown in Fig. 2. Globulin, but not albumin, secretion coincides very closely with "excess" tocopherol over the whole period, with "excess" carotene from the second day onwards, and with "excess" vitamin A from the third day onwards.

At the onset of lactation the quantity of "excess" carotene and vitamin A secreted was not as large as would have been expected from the amount of globulins present. Two explanations can be offered for this. Firstly, the composition of the globulin fraction secreted in the milk may not remain the same, and could at the start of lactation contain a higher proportion of blood-plasma proteins with which

carotene and vitamin A are not associated. Secondly, and more probably, the composition and origin of milk fat may change during the first few days of lactation. The calculations of "excess" carotene, vitamin A, and tocopherol are based on the assumption that, apart from material introduced in protein-bound form, the concentrations of these substances in the milk fat are uniform during at least the first 14 days of lactation. This may be valid only if the origin of the fat remains the same over this period. The iodine values and Reichert values recorded in Fig. 1 show changes in composition which indicate a changing origin of the milk fat. These fat constants indicate a limited mammary-gland synthesis with a greater dependence on blood lipids at the very start of lactation. The blood lipids include fats of immedaite dietary origin, mobilised body depot fats and fats from liver synthesis. There is no precise information regarding the quantities of fat-soluble vitamins associated with blood lipids from these three sources, but with the high carotene and tocopherol intake of pasture-fed cows it can be presumed that dietary fat in transport from the intestines would carry a much higher concentration of carotene, vitamin A, and tocopherol than would blood lipids of other origins. Any excessive drawing on body-fat reserves or liver-synthesised fat at the very start of lactation would thus result in the uptake by the mammary gland of blood lipids whose average vitamin content was lower than would be the case once normal lactation was established. The contributions of protein-bound forms of carotene, vitamin A, and tocopherol to colostral levels of these substances would therefore have been greater than the "excess" secretions shown in Fig. 3. The discrepancies between the true amounts of carotene, vitamin A alcohol, and tocopherol taken up by the mammary gland in protein-bound forms and the "excess" secretions shown in Fig. 3 would not necessarily be the same for each vitamin and would depend largely on the extent to which the vitamins associated with body fats were also mobilised with them. If mobilisation of fat-soluble vitamins bears any relationship to the quantities present in body fats, blood lipid derived from these fats might be expected to contain relatively large amounts of tocopherol, some carotene, but only traces of vitamin A. This would mean that the differences between the "excess" secretions calculated for vitamin A and the quantity of protein-bound vitamin alcohol actually taken up by the mammary gland at the onset of lactation were fairly large. The errors would be less for carotene and smaller still for tocopherol. If allowance could be made for the errors, the effect would be to raise the "excess" secretions shown in Fig. 3 so as to bring secretions of carotene, vitamin A, and tocopherol more into line with the globulin secretion curve.

The results presented here provide strong quantitative evidence in support of the previous suggestions (Thompson and McGillivray 1957; McGillivray 1957b) that the decrease near parturition in blood-plasma carotene and vitamin A is related to the extra drain for colostrum production and that these substances are taken up by the mammary gland along with the proteins with which they are associated in the blood plasma. It would appear that similar considerations apply to tocopherol, and possibly to other fat-soluble materials. It would seem

too that relationships between blood plasma and colostrum protein could be placed on a quantitative basis. For example, in the present investigation, although plasma proteins were not determined for individual animals, the average protein loss from the blood plasma, calculated as for the fat-soluble vitamins, was 300 g and the average quantity of globulin secreted over the first six milkings was 340 g.

If further information can be obtained regarding the particular proteins with which the fat-soluble vitamins are associated in blood, and the extent to which the vitamins are mobilised with body fat, it seems that carotene, vitamin A, and related materials might prove useful markers with which to study the uptake of blood lipids and proteins by the mammary gland under normal and abnormal conditions.

Acknowledgements

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POTATO VIRUSES A AND S IN NEW ZEALAND

By A. D. Thomson, Plant Diseases Division, Department of Scientific and Industrial Research, Lincoln

(*Received for publication, 29 April 1959*)

Summary

Potato virus A has been identified in the potato varieties Arran Chief and Aucklander Short Top. Potato virus S has been identified by serological tests in the varieties Aucklander Short Top, Arran Banner, and Dakota.

Introduction

Potato viruses X, Y, leaf roll, and aucuba mosaic, have been recorded as occurring in New Zealand potato varieties (Chamberlain 1954). The present study, which gives evidence for the presence of viruses A and S in New Zealand potatoes was particularly concerned with the development of a suitable test for these viruses. Although potato virus A is widespread in Europe, North America, and Australia, it had not previously been isolated in New Zealand. Virus A resembles Virus Y in some of its properties and a further study of the relationship between these two viruses is required. Potato virus S was first isolated in Holland (Bruyn Ouboter 1952) and occurs in many countries. Virus S resembles Virus X in that most potato varieties are symptomless "carriers" and transmission in the field appears to be by contact between infected and healthy plants and by cultivating operations (Macarthur 1956). Viruses X and S are not, however, serologically related (Bruyn Ouboter 1952).

Methods

All plants were grown in composted, steam-sterilised soil and were maintained in glasshouses which were heated in winter. Fine-grained carborundum powder was used in sap-inoculation experiments. *Myzus persicae* Sultz. was used for virus A transmissions as described by MacLachlan *et al.* (1953). Virus S was identified serologically by the agglutination technique (van Slogteren 1955).

Results

Potato Virus A

When aphids were fed on virus-Y-free plants of the varieties Aucklander Short Top and Arran Chief and then transferred to *Nicotiana tabacum* L. (var. White Burley), slight vein-clearing followed by mild vein-banding or mottle symptoms developed on the tobacco plants; these are the symptoms reported for virus A (MacLachlan *et al.* 1953). Virus Y produces similar symptoms on tobacco although the symptoms appear sooner and are more severe. Whereas the combination of most virus X strains with virus Y produces a severe synergistic reaction ('spot-necrosis') on tobacco, no such synergistic reaction is known to occur between viruses X and A.

In sap-inoculation experiments using inoculum from virus-Y-free Aucklander Short Top and Arran Chief plants, *Lycopersicum pimpinellifolium* (Jusl.) Mill reacted with local and systemic necrosis (Fig. 1). Again these are the symptoms reported for virus A (MacLachlan *et al.* 1953). None of the virus X strains (Thomson 1956) or virus Y isolates from New Zealand potatoes produced necrotic symptoms on *L. pimpinellifolium*. Thus, this test-plant may be useful for identifying virus A when present in multiple infections with viruses X and Y.

Fig. 1.—Symptoms of potato virus A on *Lycopersicum pimpinellifolium*. Right: Systemic necrosis after sap-inoculation with virus A from Arran Chief. Left: Healthy leaf.

Photo: C. J. Miles

A number of *Solanum demissum* Lindl. selections have been reported as localised-reacting test-plants for virus A, and two of these, G1868 (b) (Cockerham 1949) and P.I. 175404 (Webb and Buck 1955) were used in the present work. Sap from virus-Y-free Champion, Aucklander Short Top, and Arran Chief, produced black local lesions on leaves of both strains although neither strain reacted consistently to inoculum from the same source.

Thus, the following tests indicate the presence of virus A in Aucklander Short Top and Arran Chief potatoes. Firstly, the symptoms on tobacco, *Lycopersicum pimpinellifolium*, and *Solanum demissum* strains G1868 (b) and P.I. 175404, and, secondly, the absence of a synergistic reaction with virus X on tobacco.

Although Arran Chief plants are relatively tolerant to virus X and virus A, plants infected with both viruses react with severe symptoms

(Fig. 2). This disease (potato crinkle) was originally shown by Murphy and McKay (1932) to be due to infection with virus X + A. A similar synergistic reaction occurs with virus X + Y (Fig. 2). Virus A does not appear to produce leaf symptoms on infected Aucklander Short Top plants. Using *L. pimpinellifolium* as the test plant, virus A was isolated from all 17 Arran Chief plants obtained from Pukekohe, which were showing crinkle symptoms. Virus A was also isolated from all 15 Aucklander Short Top plants tested, including 5 virus-Y-free selections made by the Department of Agriculture, Dunedin.

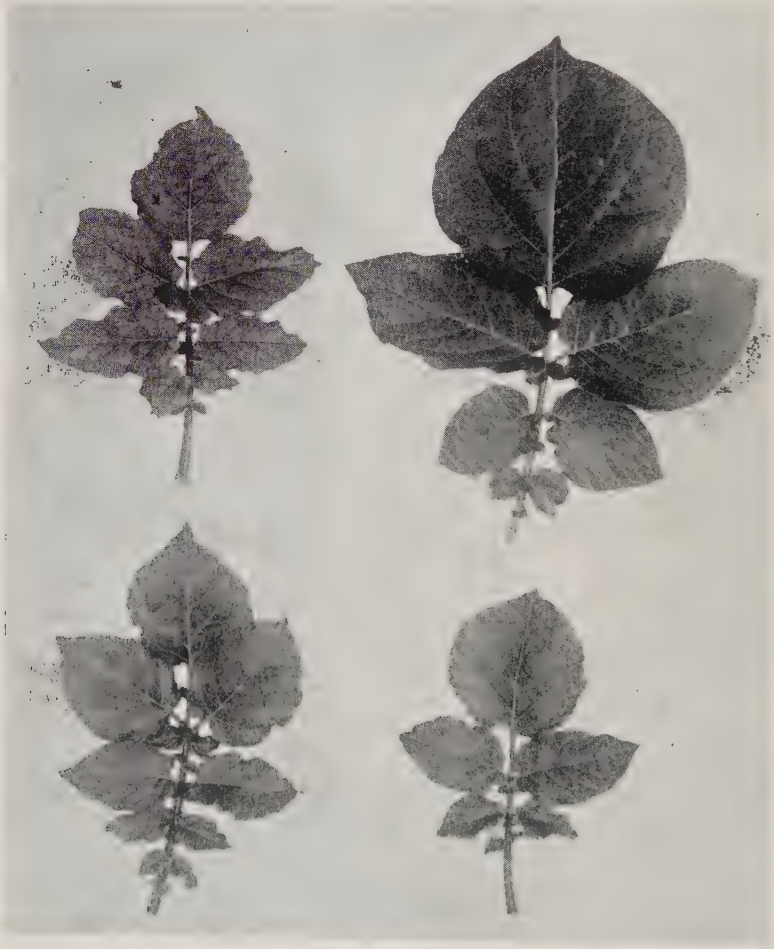

Fig. 2.—Symptoms of potato viruses X, Y, and A on Arran Chief.
Top left: mottle and leaf crinkle due to virus X + Y infection.
Top right: "masked" virus X infection.
Bottom left and right: mottle and crinkle due to virus X + A infection.

Photo: C. J. Miles

Potato Virus S

Yarwood and Gold (1955) reported that *Cyamopsis tetragonoloba* (L) Taub. produced local lesions to virus S. However, in tests at Lincoln, using a virus S isolate from a Russet Burbank potato, *Cyamopsis* did not produce a specific response to virus S. All tests on New Zealand potatoes were made with authentic virus S antisera from the Institute of Flowerbulb Research, Lisse, The Netherlands.

Virus S was present in all 23 Aucklander Short Top plants (Redmond strain) tested, including 5 virus-Y-free selections made by the Department of Agriculture, Dunedin. All 10 Arran Banner and 12 out of 17 Dakota plants tested were infected. All Ilam Hardy (12 plants tested) and Arran Chief (23 plants tested including 17 from virus-free stocks) were free from virus S. Plants from the following imported American varieties were also infected:

Russet Burbank, Teton, Early Gem, Red Warba, Red Pontiac, Keswick, Green Mountain, Cherokee, Earlaine, and White Rose.

DISCUSSION

Chamberlain (1940) first reported the presence of "masked" virus X in the potato variety Aucklander Short Top and his experiments indicated that virus Y was also present. This was confirmed later by Procter (1952). The tests described here indicate that in addition to viruses X and Y, viruses A and S may be present in Aucklander Short Top. Although Aucklander Short Top has been considered a "masked carrier" of viruses, plants free from virus Y are much more vigorous than the infected plants (Thomson 1957).

It is probable that virus S is transmitted in the field by contact (Rozendaal and Brust 1955; Macarthur 1956), and its abundance in potatoes is partly due to the difficulty in identifying infected plants and partly to the tendency of infected plants to produce a large proportion of seed-sized tubers (Macarthur 1956). Since virus S has been considered to reduce the tuber yield of some potato varieties by from 10% to 20% (Munster and Pelet 1954; Rozendaal and Brust 1955), selection and increase of virus-S-free plants may be justified.

Further studies on the incidence of viruses A and S in the more important New Zealand potato varieties is required. The most satisfactory test-plant for virus A so far available is *Lycopersicum pimpinellifolium*. It should be possible to do large-scale tests for virus S by the serological field-testing technique already used for virus X.

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THE EFFECT OF STOCKING UPON A COMPARISON OF BREAK AND ROTATIONAL PADDOCK GRAZING FOR DAIRY COWS

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Summary

The differences between milk, butterfat, and herbage yields per acre at overall stocking rates of 1.15 and 1.52 cows per acre were compared with the differences between the effects of break and rotational paddock grazing.

Twenty-one pairs of identical-twin cows were divided into three treatment groups. Treatment 1 cows were paddock grazed at the lower overall stocking rate; treatment 2 and 3 cows were break and paddock grazed respectively, at the higher overall stocking rate. The average grazing concentrations for treatments 1 to 3 were 10, 106, and 14 cows per acre, respectively. The breaks for treatment 2 cows were moved forward twice daily and the cows in treatments 1 and 3 were given a fresh paddock each day.

The experiment started on 4 October 1957, and finished fifteen weeks later on 16 January. This was the main period of spring pasture growth. There was no intention of testing the three treatments under conditions when it might be desirable to ration out feed when it is scarce.

Neither rate of stocking nor grazing management affected milk or butterfat yields per cow, but in comparison to treatments 1 and 3 the cows which were break grazed had 4%–5% lower feed intakes and 7%–10% better gross efficiencies of conversion of feed into milk. Both effects were statistically significant.

Stocking rate had a stronger influence upon production per acre than did grazing method. The 32% higher rates of stocking in treatments 2 and 3 caused increases of about the same order in milk and butterfat yields per acre and an increase of about 10% in yield of digestible organic matter per acre.

At the higher rate of stocking, one quarter of the break-grazed area was cut for silage, but none was taken from the paddock-grazed area. This was probably due to a combination of feed saved through lower intakes per cow and the greater ease with the break-grazing system of appreciating when a small surplus of grass is available for conservation. There was little difference between the total yields of digestible organic matter per acre from the areas break and paddock grazed at the higher rate of stocking.

Introduction

In summing up the three previous investigations of "break" and rotational "paddock" grazing at Ruakura, McMeekan (1956) said that they had "failed to demonstrate any superiority of the break over the

* Work done at Ruakura under a New Zealand National Research Fellowship.

paddock grazing system as a method of feeding dairy cows *during the main period of pasture growth.*" This did not agree with the conclusions from some overseas trials. For example, in the British experiment reported by Holmes *et al.* (1952) the production per acre in terms of starch equivalent was higher by 20%–40% with break grazing than with rotational paddock grazing.

The important difference between the plans of these experiments was that at Ruakura the overall stocking rates had been the same on both systems of management, whereas in Britain the overall stocking rate on the break-grazed area was 30% higher than on the paddock grazed area. This prompted McMeekan and Hancock (1954) to point out that with such a difference in stocking rate in the British experiment it is not possible to assess just how much of the additional output was due to grazing system. New Zealand results have illustrated the powerful effect of stocking rate *per se* on production per acre, and it is possible that this factor and not the grazing management might have been the major cause of the increased yield per acre under break grazing.

The object of the fourth experiment in the Ruakura series has been to test whether this explanation was true.

Experimental

Treatments

It was intended to compile a "balance sheet" of grass, milk, and fat productions during the spring and early summer of 1957 from three areas of grassland, each divided into a number of paddocks.

On one area (Treatment 1) the overall stocking rate was 1.15 cows per acre, and the paddocks were grazed in rotation.

On the second area (Treatment 2) the overall stocking rate was 1.52 cows per acre, and the paddocks were break grazed.

On the third area (Treatment 3) the overall stocking rate was 1.52 cows per acre, and the paddocks were grazed in rotation.

It was hoped that the results from treatment 3 would test whether any advantage in treatment 2 over treatment 1 was due primarily to a difference in rate of stocking.

Management of Treatment Groups

Each treatment was managed independently of the other two, but the following principles were adhered to:

Break Grazing. A fresh break was given after each milking. The size of break was adjusted so that feed intake was not restricted, but that in satisfying their appetites the cows ate the grass down to a height of 2–3 inches. Back grazing was allowed, as in previous Ruakura trials.

Paddock Grazing. Cows on treatments 1 and 3 grazed a fresh paddock each day. No fixed order of grazing the paddocks was followed on any treatment.

Silage and Hay. Whenever there was an excess of grass ready for grazing, one or more paddocks were dropped from the rotation and cut for silage or hay.

Water. There were water troughs in all paddocks, and at the milking shed.

Milking. All groups were milked twice daily, at about 5.0 a.m. and 3.0 p.m.

Cows. Twenty-one pairs of identical-twin Jersey-grade cows were allocated to the three treatments according to a balanced incomplete-block design, where each pair of twins constituted a block. The design, which is illustrated in Table 1, resulted in fourteen cows being placed on each treatment and allowed full use to be made of the twins in the

TABLE 1. DISTRIBUTION OF THREE PAIRS OF IDENTICAL-TWIN COWS BETWEEN THREE TREATMENTS

Twin Pair No.	Treatment		
	1	2	3
1	1A*	1B*	
2		2A	2B
3	3A		3B

* A and B represent a pair of twins allocated at random with one animal going to each of the treatments shown.

statistical analysis of the results. The cows had been in milk for about two months prior to the start of the experiment, and no pair was included which had produced dissimilar levels of milk and fat during this period. In each treatment group about 30% of the cows were in their first and second lactation, about 50%–55% were in their third and fourth lactation and about 15%–20% were in their fifth to eighth lactation.

Paddocks. The experiment was located at the Ruakura No. 5 Dairy. Nine fields were each split into three paddocks with the area ratios 4 : 3 : 3. One paddock in each field was allocated to each treatment; the largest paddock always being for treatment 1 to achieve the lower overall stocking rate called for in the plan. The areas of the paddocks are given in Table 2.

The herbage on most fields was predominantly perennial ryegrass and white clover, but in one there was a high proportion of cocksfoot. The soil type was brown loam on five fields and clay loam on the re-

maining four. The manurial treatment had been an annual autumn application of 2 cwt serpentine superphosphate per acre. Previous grazing had been with dairy cows and their followers.

TABLE 2. AREAS OF PADDOCKS IN ACRES

	Treatment		
	1 Low-stocked Paddock-grazed	2 High-stocked Break-grazed	3 High-stocked Paddock-grazed
Field No.			
2	1.23	0.92	0.92
5	0.96	0.72	0.72
6	1.58	1.19	1.19
7	1.59	1.19	1.19
8	1.58	1.19	1.19
14	1.17	0.87	0.87
15	1.24	0.93	0.93
17	1.14	0.86	0.86
24	1.73	1.32	1.32
Total acreage	12.22 (100)	9.19 (75)	9.19 (75)

Animal Production

Measurements were made of live-weight changes and the amount and fat test of the milk produced by each cow. The cows were weighed individually on four consecutive days at the start and finish of the experiment, and at twice weekly intervals in between. The milk yield of each cow was recorded at each milking and an aliquot sample was taken for twice-weekly fat analyses.

Herbage Production

To assess the effect of treatment upon herbage production it was essential to know (a) the amount of herbage on the paddocks at the start and finish of the experiment, (b) the amount consumed by the cows, and (c) the amount mown for conservation.

Herbage Cover on Paddocks. This was estimated by mowing sample strips. At the start of the experiment all were mown with a Dennis machine with a 2 ft rotating drum blade set to cut 1 inch from the ground. Because of the length of the grass in some paddocks at the finish, two cuts had to be taken on each strip. The top cut was with a Gravely reciprocating blade machine and the second cut was with the Dennis set as before.

Herbage dry matter was analysed for lignin, and the digestible organic matter was estimated using Lancaster's (unpublished) modification for Ruakura feeds of an equation published by Lancaster (1944). The modified equation is $y = 9.24 - 2.42x$; where y is the per cent digestibility of herbage organic matter and x is the per cent lignin in the herbage dry matter.

Herbage Consumed by Cows. The weekly intake of digestible organic matter by each cow was obtained from measurements of faecal output and feed-to-faeces ratio. The former was determined using the chromic oxide marker technique and the latter from an equation modified in the light of recent evidence from one used previously at Ruakura (Lancaster 1954, Carter unpublished). The equation is $y = (7.4 \log (n - 1) + 0.4)x$; where y is weekly intake of digestible organic matter in pounds, n is per cent nitrogen in the faeces dry matter and x is the total weekly output of faeces organic matter. The routine field operations involved in these methods, and used in the experiment reported here, have been described by Wallace (1956).

Herbage Mown for Conservation. When herbage was cut for silage it was all loaded on lorries and weighed. When it was cut and made into hay, the bales were counted and about one in four was weighed. In both cases cut and wasted herbage which remained on the paddocks after harvesting was estimated by raking and weighing from sample areas. These estimates were added to the dry matter harvested to give the total weights of herbage dry matter cut per paddock. Weights of digestible organic matter cut were estimated from the lignin contents of the dry matters.

Duration of Experiment

The experiment started on 4 October 1957. It was concluded after fifteen weeks on 16 January 1958, because it was thought that the cows on the two high-stocking-rate treatments could no longer be full fed. One essential feature of the experiment was that the treatments were to be tested at the season of maximum grass growth and not during a period when the grass should be rationed to make best use of a limited feed supply.

Meteorological Records

These were available for the period of the experiment from the meteorological sub-station which is situated about one mile from No. 5 Dairy on the Ruakura sheep farm.

RESULTS

Within the first fortnight of the experiment three cows became sick, and they and their twins were replaced by three other twin sets. There were also several cases of bloat during the first week, but these were not severe enough to have any lasting effect upon milk production. After the first fortnight all animals remained in excellent health.

Some meteorological data for the period of the experiment are given in the Appendix. The spring and early summer were cool, and the spring flush of grass was not as marked as is usual at Ruakura. However, the growth was well maintained and did not decline until early January.

Statistical Analyses

The data showing the effects of treatments upon milk and butterfat production per cow were analysed statistically both before and after co-variance adjustments were made for production during the four-week pre-experiment period. These adjustments reduced the variability within twin sets and almost eliminated variability between twin sets. The data available did not allow similar adjustments to be made before the feed intakes and gross efficiencies of conversion of feed into milk were analysed.

As the experiment was not replicated on different areas of land it was not possible to analyse statistically the effects of treatments upon live-weight changes per acre, or on herbage, milk, and butterfat productions per acre. To ensure that all data presented are on the same basis, unadjusted group means have been given in all cases. Where reference to statistical significance is mentioned comparisons have been made on an adjusted twin-pair basis.

Stock Concentrations

The stock concentrations at any one time are illustrated in Fig. 1. In treatments 1 and 3, with daily shifts of paddocks, the concentrations averaged 10.3 and 13.7 cows per acre, respectively. In treatment 2, the concentration on each half-day's break averaged 106.2 cows per acre. This takes no account of back-grazing, which was of minor importance compared with the fresh break.

These figures indicate the essential differences between the treatments tested, but it should be noted from Fig. 1 that there were considerable variations around the means, particularly with break-grazing.

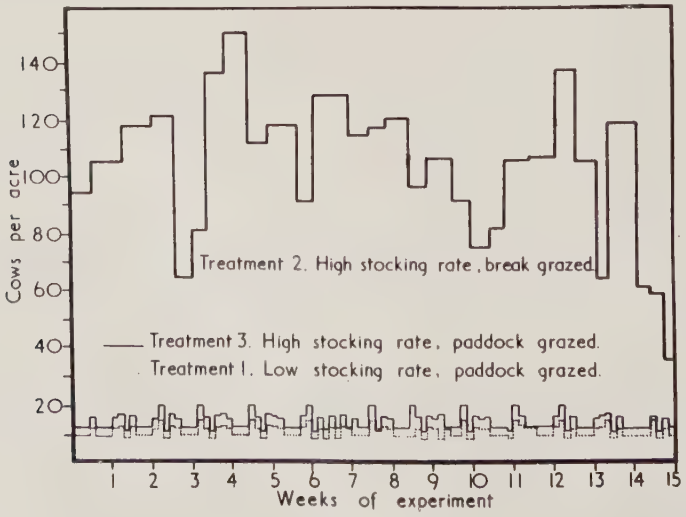

Fig. 1.—Stock concentrations per acre.

Feed Intake and Production Per Cow

Means of the twice-weekly live weights and of weekly yields of milk and fat are shown in Fig. 2, while the total productions per cow during the 15 week experimental period are summarised in Table 3 together with data for feed intakes and gross efficiencies of conversion of feed into milk.

Although it was intended that the break-grazed cows should be full fed, they each consumed about 5% less digestible organic matter than animals from the other two treatments (P. 0.01). However, as they

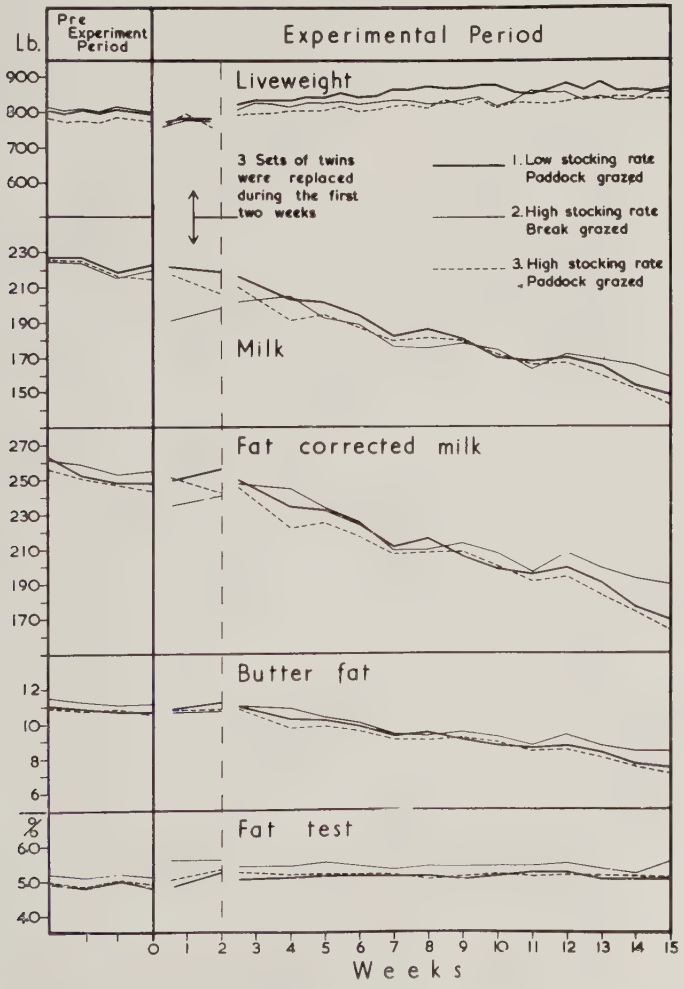

Fig. 2.—Average live weights and weekly average milk and butterfat yields.

TABLE 3. FEED INTAKES AND MILK AND FAT PRODUCTIONS PER COW IN 15 WEEKS

	Treatment					
	1 Low-stocked Paddock-grazed		2 High-stocked Break-grazed		3 High-stocked Paddock-grazed	
Intake of d.o.m.* (lb)	2329	(100)	2202	(95)	2314	(99)
Live-weight increase (lb)	70	(100)	59	(84)	62	(89)
Milk (lb)	2769	(100)	2707	(98)	2690	(97)
Butterfat (lb)	140	(100)	144	(103)	136	(97)
Fat corrected (4%) milk (lb)	3204	(100)	3245	(101)	3119	(97)
Intake of d.o.m.* per lb f.c.m.* produced (lb)	0.74	(100)	0.69	(93)	0.76	(103)

* d.o.m. = digestible organic matter, f.c.m. = fat-corrected milk.

also had 7–10% better gross efficiencies of conversion of feed into milk (P 0.01) their milk and butterfat yields were not reduced.

Neither rate of stocking nor method of grazing affected the yields per cow of milk, butterfat, or fat-corrected milk, for the difference between treatment means were both small and without statistical significance.

The figures in Table 3 suggest that the high rate of stocking reduced live-weight gain, but this effect varied between individuals and was not statistically significant. On average, the break-grazed cows gained 3 lb less than those paddock-grazed at the high rate of stocking, but this was neither statistically significant nor sufficiently large to account for the treatment difference in gross efficiency of conversion of feed into milk.

Animal Production Per Acre

Table 4 shows that the greatest differences in animal production were due to the 32% higher rate of stocking in treatments 2 and 3, which caused increases of about the same order in yields per acre of milk, butterfat, and fat-corrected milk. Differences in live-weight increase per acre were not as large, but no significance can be attached to this observation because it did not arise from a consistent treatment effect.

Grazing method had no significant influence upon milk and butterfat productions per acre, which follows from its lack of influence on production per cow.

Herbage Production

The total productions of digestible organic matter (d.o.m.) per acre were higher by about 10% on the areas stocked at the higher rate than

TABLE 4. ANIMAL PRODUCTION PER ACRE IN 15 WEEKS

	Treatment					
	1 Low-stocked Paddock-grazed		2 High-stocked Break-grazed		3 High-stocked Paddock-grazed	
Live-weight increase (lb)	80	(100)	90	(113)	95	(119)
Milk (lb)	3174	(100)	4122	(130)	4097	(129)
Butterfat (lb)	160	(100)	219	(137)	207	(129)
Fat-corr. (4%) milk (lb)	3673	(100)	4941	(135)	4749	(129)

on the area stocked at the lower rate (Table 5). There was also a slight increase in production with break-grazing but undue importance should not be given to this small effect, which cannot be appraised statistically.

TABLE 5. HERBAGE PRODUCTION PER ACRE IN 15 WEEKS

	Treatment					
	1 Low-stocked Paddock-grazed		2 High-stocked Break-grazed		3 High-stocked Paddock-grazed	
Herbage eaten by cows (lb d.o.m.*)	2668		3355		3526	
Herbage harvested for conservation (lb d.o.m.)	285		326		0	
Increase in herbage cover on paddocks† (lb d.o.m.)	482		146		203	
Total production per acre (lb)	3435	(100)	3827	(111)	3729	(109)

* d.o.m. = digestible organic matter.

† Herbage cover per acre at finish of experiment minus herbage cover per acre at start of experiment (see Table 6).

Although the yields of digestible organic matter on treatments 2 and 3 were similar there were important differences between the ways in which they were made up. Tables 5 and 6 show that with break grazing (treatment 2) there was less feed (d.o.m.) grazed off by the cows and slightly less feed (d.o.m.) remaining on the paddocks at the end of the experiment—but that it had been possible to cut 326 lb digestible organic matter per acre for conservation as silage. With paddock grazing at the same overall rate of stocking no herbage was cut for conservation.

The average amounts of herbage growing on each acre at the start and finish of the experiment are shown in Table 6 together with the average amounts which were cut for hay and silage. These data are given in terms of both dry matter and digestible organic matter.

TABLE 6. SOME DETAILS OF HERBAGE PRODUCTION PER ACRE

	Treatment		
	1 Low-stocked Paddock-grazed	2 High-stocked Break-grazed	3 High-stocked Paddock-grazed
Cover on paddocks at start of experiment: lb dry matter	1125	1092	1231
lb d.o.m.	783	759	855
at finish of experiment: lb dry matter	2202	1517	1767
lb d.o.m.	1265	905	1058
Cut for silage: lb dry matter	271	474	—
lb d.o.m.	173	326	—
Cut for hay: lb dry matter	217	—	—
lb d.o.m.	112	—	—

Twenty-six per cent of the strip-grazed treatment 2 area was cut for silage on 15 November. The two paddocks involved were both of 1.19 acres, and they yielded 1819 lb and 2535 lb dry matter. The percentages of lignin in the dry matter were 6.2 and 7.2 respectively.

None of the paddock-grazed treatment 3 area was cut for conservation, but 22% of the lower-stocking-rate paddock-grazed treatment 1 area was cut for silage and hay. One paddock, of 1.58 acres, was cut for silage on 20 November and yielded 3307 lb dry matter. A second paddock of 1.14 acres was cut for hay on 7 January 1958, and yielded 2646 lb dry matter. Lignin made up 8.9% and 14.9% of the dry matter in the herbage cut for silage and hay respectively.

DISCUSSION

The suggestion of McMeekan and Hancock (1954) that the considerable advantages of break grazing in some overseas trials were due mostly to higher rates of stocking, was supported by the main conclusion from this experiment, which was that rate of stocking exerted a very much stronger influence than grazing management upon both herbage and animal productions per acre. These comments apply to grazing management during the main period of spring growth, when the various experiments were carried out. At other times of the year grazing management may assume a greater importance in making the best use of feed shortages.

Although rate of stocking had the dominant effect upon production per acre, the data from this experiment did not fully support the suggestion that there is no difference between the effects of break and paddock grazing. At the higher rate of stocking, break grazing did allow one quarter of the area to be cut for silage whereas none was taken from the paddock-grazed area. There were two main reasons for this difference.

Firstly, the break-grazed cows ate less and so left more herbage cover on the paddocks. One explanation for this could have been an over-severe restriction in size of the half-daily break coupled with a reduced opportunity for selective grazing, but there are other possibilities. For example, the small area of a half-daily break could restrict activity and so lower the energy requirement for maintenance—which might have the observed effects of improving the gross efficiency of conversion of feed into milk and of reducing appetite.

Secondly, small surpluses of grass are more easily seen with break-grazing than with a system in which each paddock is grazed very much more laxly about once every eight days. These surpluses, depending on judgment, can then be cut for silage. This occurred in the experiment reported here, and it was reflected to some extent by the slightly smaller amount of herbage which remained in the break-grazed area at the end of the experimental period. It is not impossible that shutting up an equivalent area of the set-stocked treatment would have materially reduced this apparent advantage without measurable loss in milk production.

One complication in drawing practical conclusions from experiments on grazing management is the lack of exact definition for the terms used. For example, rotational "paddock-grazing" in this experiment was a system by which the stock were grazed at concentrations of 10–14 cows per acre and moved to a fresh paddock each day. In recommendations given to farmers seeking high-pressure production, however, rotational "paddock-grazing" has involved stock concentrations of 20 or sometimes even 30 cows per acre with a daily shift of paddocks. It is clear that the two systems are not the same although they are given the same name. In effect, "paddock-grazing", which involves sub-division of a farm into paddocks of two or three acres for a 60 cow herd, is part way between the systems of "paddock-grazing" and "break-grazing" which we compared. Therefore, this degree of sub-division should help in achieving the advantages of break grazing in our experiment—namely, slight restrictions in feed intake which should not affect yields and a greater ease in appreciating when a small surplus of grass accumulates and is available for conservation.

Acknowledgement

Special thanks are due to Mr. F. Parker, the technician responsible for handling the cattle throughout the experiment. Dr. A. H. Carter assisted with statistical interpretation and Miss S. Pierard with the necessary computations.

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APPENDIX

SOME METEOROLOGICAL DATA FOR THE EXPERIMENTAL PERIOD

Date	October			November			December			January		
	Max. air temp. °F.	Min. temp. on grass °F.	Rain fall in.	Max. air temp. °F.	Min. temp. on grass °F.	Rain fall in.	Max. air Temp. °F.	Min. temp. on grass °F.	Rain fall in.	Max. air temp. °F.	Min. temp. on grass °F.	Rain fall in.
1				60	47	—	67	35	.01	74	43	.09
2				63	42	.02	62	41	—	67	54	—
3				66	51	—	65	38	—	65	33	—
4	60	40	.60	62	35	.13	74	31	.42	66	32	.25
5	58	36	.11	62	31	—	65	45	.20	62	40	.39
6	59	34	.01	66	31	—	64	39	.06	66	43	—
7	60	28	—	68	27	—	64	37	—	71	38	—
8	56	28	.06	72	26	—	65	51	.07	72	43	.01
9	59	36	.20	69	31	.23	67	42	—	75	51	—
10	61	33	.03	68	58	.16	68	33	.04	73	37	—
11	66	38	.51	64	37	.15	70	52	.16	69	30	—
12	63	52	.21	66	37	.35	73	60	—	69	35	—
13	61	39	.73	64	39	.29	74	43	.02	73	44	.01
14	59	37	.09	61	42	.01	78	61	.02	75	49	—
15	60	40	—	63	36	—	71	62	.17	71	36	—
16	66	29	—	66	32	.01	70	40	—	77	44	—
17	65	33	1.06	71	50	—	72	32	.90			
18	61	48	.52	73	57	—	63	55	.39			
19	66	43	—	73	58	—	64	34	.06			
20	61	44	.25	71	52	.45	66	34	—			
21	65	38	.02	64	41	.02	67	30	—			
22	59	35	.09	65	32	—	72	44	—			
23	61	39	.03	68	38	.13	67	41	—			
24	64	27	—	66	55	.06	71	38	—			
25	62	28	.09	73	36	—	67	40	—			
26	62	38	.16	70	56	—	72	38	-			
27	62	29	.01	75	57	.99	70	49	.05			
28	62	38	.02	63	51	—	69	50				
29	65	36	.07	65	35	—	72	32	—			
30	65	56	.02	64	28	.02	66	48	.14			
31	61	34	.04				72	51	—			

NUTRIENT RETURN IN LITTER AND RAINFALL UNDER SOME EXOTIC CONIFER STANDS IN NEW ZEALAND

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Summary

Because changes in the nutrient content of the soil after afforestation may result in slower growth of succeeding tree crops, a study is being made of the changes taking place in pumice soils under exotic conifers in New Zealand. As litter plays a large part in determining the future nutrient status of the soil, monthly litter-fall collections have been made for several years under radiata pine, Corsican pine, Douglas fir, and European larch. The nutrient compositions of the litters are similar to those reported from other countries but the total annual weights of litter fall are greater in New Zealand. The air-dry weight of litter falling under both radiata and Corsican pines exceeded 8000 lb/ac in one year and averaged more than 5000 lb/ac/yr. The rate of needle fall under Douglas fir does not vary greatly with season but most Corsican-pine needles fall in the autumn. Under radiata pine there is also a peak needle fall in the autumn but considerable quantities of needles fall throughout the year, especially in young stands. Storms influence the fall of twigs from all species.

Rain as it penetrates the tree crowns of radiata pine and Douglas fir removes considerable quantities of potassium and phosphorus. The annual rainfall reaching the ground under Douglas fir contains twice as much potassium and approximately the same amount of phosphorus as the litter fall. This removal of nutrients from the tree crowns reaches a maximum in the late summer and autumn.

The greater uptake of sodium on a high-sodium soil is discussed.

Introduction

In the central North Island of New Zealand large areas of exotic coniferous trees have been planted on pumice soils. The continuation of the present rapid and healthy growth of these forests is of great economic importance to the country, because of the establishment of large timber-using industries based directly upon them.

As yet, little is known of the changes in the fertility of the pumice soils that will eventually be brought about by the growth of successive rotations of coniferous tree crops. Experimental work was commenced in 1953 to study tree-soil relationships from the nutritional point of view. As part of these studies, litter has been systematically collected and analysed from beneath stands of the most important species—radiata pine (*Pinus radiata* D. Don), Corsican pine (*Pinus nigra* Arn. (laricio)), Douglas fir (*Pseudotsuga taxifolia* (Poir.) Britt.) and European larch (*Larix decidua* Mill.).

It seems that the only data for radiata-pine litter have been obtained by Kittredge (1940) in California. However, the amount and

content of litter falling under other conifers has been studied by many workers. Alway and Zon (1930) summarised investigations that had been carried out in central Europe and reported results for pine stands in the U.S. More recently, extensive surveys of litter fall have been carried out in many countries. Papers included in a literature review by Blow (1955), and those by Tarrant *et al.* (1951) and Scott (1955), report the results of studies in the U.S. Owen (1954) has studied monthly variations in the amount and content of litter fall of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) growing in Wales, and the litter of Norway spruce (*Picea abies* (L.) Karst.) and other conifers in Scandinavia has been investigated in several studies (e.g., Romell 1939; Mork 1942: Lindbergh and Norming 1943; Bonevie-Svendsen and Gjems 1957).

In studying the rate of release of mineral nutrients from decomposing radiata-pine litter in the field, the writer found that the quantities of potassium and sodium in rainwater which had penetrated the litter and humus layers were greater than could be accounted for by litter decomposition. The annual litter fall per square yard contained 39 me. of potassium and 26 me. of sodium, but the quantities found in the rainwater reaching the mineral soil were 60 me. and 105 me. respectively. This led to the analysis of rainwater collected beneath trees, as it had been shown (e.g. Mes 1954) that rain can remove considerable quantities of some mineral elements from foliage, and Tamm (1951) found that under three species of forest trees significant amounts of nutrients reach the soil in rainwater which has penetrated the tree canopy.

In 1954 the collection of rainwater under radiata pine was begun, and in 1955 Douglas fir was included in the study. Preliminary results have been reported (Will 1955).

Experimental Sites

Collection sites were selected in two forests of exotic conifers on the central volcanic plateau of the North Island (Rotorua Conservancy). The region lies within 50 miles of the sea and has a mean annual temperature of 50°F. The annual rainfall of 60 in. is fairly evenly distributed throughout the year, the driest month being March (3.7 in.) and the wettest June (5.7 in.).

Sites A, B, D, E, and G (see Table 1) in Whakarewarewa Forest are on Rotomahana shallow sandy loam, and sites C and F in Kaingaroa Forest, 30 miles to the south-east, are on Paengaroa shallow sand (N.Z. Soil Bureau 1954).

Rotomahana shallow sandy loam comprises 4–6 in. of brown sandy loam (Rotomahana "mud" erupted 1886) over a buried soil (black sand on yellow-brown silty sand) derived from rhyolitic pumice (Taupo and Mamaku ashes). Paengaroa shallow sand consists of 4–6 in. of black, very friable sand (Kaharoa ash) on dark-brown and yellow-brown silty sand (Taupo ash). Both soils are derived from rhyolitic pumice and they differ mainly in the properties of the surface horizons.

TABLE 1. DESCRIPTION OF LITTER AND RAINFALL COLLECTION SITES

Species	Site	Location	Date of Planting 19—	No. of Live Trees/acre 1957	Av. Ht. 1957 (ft)	Crown Cover %	Other Vegetation	Start Litter Colln.	No. of Trays
Radiata	A	Whaka.	48*	1500	50	75–80	Scattered native ferns and broad-leaved shrubs.	Jul 53	6
Radiata	B**	Whaka.	15	100	125	50–55	Numerous native ferns and broad-leaved shrubs.	Jul 53	6
Radiata	C**	Kainga.	28	120	120	65–70	Scattered ferns.	Nov 55	6
Corsican	D	Whaka.	11	360	100	85–90	Nil.	Jul 54	3
Douglas	E	Whaka.	15	450	100	100	Nil.	Jul 54	3
Douglas	F**	Kainga.	23	500	90	100	Nil.	Jul 55	8
Larch	G	Whaka.	11	350	85	80–85	Numerous native ferns and broad-leaved shrubs.	Jul 54	3

* Natural regeneration following clear felling in 1947.
** Sites at which rainfall was collected in addition to litter.

None of the stands has been thinned, but mortality following attacks by the wood wasp *Sirex noctilio* Fabr. has considerably reduced the stocking of radiata pine at sites B and C.

METHODS

Litter Collection

In July 1953, litter collection was begun under radiata pine at two sites in Whakarewarewa Forest. The collection trays were made of fine-mesh galvanised gauze supported on wooden frames three-feet square. Trays were placed at random, over an area of up to an acre, at each site, and at approximately monthly intervals the accumulated litter was removed from each tray. After air drying, the litter was divided into two parts—(1) needles and (2) other litter (twigs, cones, and bark)—which were then weighed separately.

Later, the collection of litter was extended to other sites and species. Details of the collecting sites are given in Table 1. In 1955 collection was abandoned at sites B and E in favour of sites C and F which are more representative of the large areas of older radiata pine and Douglas fir in the Rotorua Conservancy.

Only the litter from the tree species being studied has been considered. Where native ferns and broad-leaved shrubs were present (see Table 1), these were cleared from the vicinity of the collection trays. At sites B and C parts of *Sirex*-killed trees have been found in the collection trays, especially after storms. As *Sirex* is now part of the

forest environment of radiata pine, particularly in the Rotorua district, this material has been included in the total weights of litter.

Rainfall Collection

From November 1954 to November 1955 rainwater samples were collected at two positions under radiata pine at site B. Another set of samples was collected about 30 yd outside the edge of the stand. At first, collections were made in 1-litre Pyrex glass conical flasks with 5½-inch glass funnels, but later a change was made to polythene containers and funnels. Small wads of cotton wool were placed in the funnel necks to minimise contamination from dust and other wind-blown material. After approximately each 4 inches of rain had fallen, samples were collected for analysis.

In April 1955, rainwater collection was started under Douglas fir at site F, and, in the following November, collection under radiata pine was discontinued at site B and commenced at site C.

There has been no evidence of contamination by bird droppings.

Methods of Analysis

After grinding and mixing of the monthly needle-litter collection from each stand, 10-g samples were oven dried and were analysed by the methods described by Metson (1956). Calcium, magnesium, potassium, and sodium were determined using a modification of the flame photometer method for soils described by Fieldes *et al.* (1951). Phosphorus was estimated colorimetrically in another aliquot. A micro-Kjeldahl technique was used to estimate nitrogen.

In dealing with twigs, bark, etc., the samples from three or four monthly collections were mixed together prior to analysis.

Rainwater samples were filtered when they were received in the laboratory; this was done to minimise any contamination due to solid matter, especially the pumice dust which is prevalent in summer over the whole district. Samples were then evaporated to dryness and placed in a furnace at 400–450°C to destroy any organic matter present. Calcium, potassium, sodium, and phosphorus were determined as for the litter samples. No determinations of nitrogen or magnesium have been made on rain-water samples.

Results and Discussion

Litter Fall

Annual Weights

Yearly total weights have been calculated for each site (Table 3). Up to the present time, litter fall under the young radiata pine at site A has included only needles and pollen cones, and no separate weights have been recorded.

As might be expected in a region where the growth rate of trees is relatively rapid, the litter fall under all species is greater than that

reported for the same or closely related species in other countries (see Owen 1954 and Wright 1956).

At individual sites there have been considerable variations in the total weight from year to year, but this is not unusual. Ebermayer (1876) found that the litter fall from *Pinus sylvestris* L. varied from 1,790 lb to 4,960 lb per acre in different years. Under *Pinus resinosa* Ait. an even larger variation of 1,640 lb to 5,500 lb per acre has been found by Lunt (1951). The very heavy fall of litter other than needles at site B in the 1953-54 period was due to storms, during which several of the trays were hit by parts of *Sirex*-killed trees.

Kittredge (1940) found that radiata pine had the greatest annual litter fall of the species he studied growing in similar environments in California. The figures in Table 3 show that, in New Zealand, radiata pine has a heavier litter fall than larch or Douglas fir, but that the annual total for Corsican pine is even larger. This may be explained by the fact that unthinned Corsican pine stands tend to remain dense with comparatively little mortality from mutual suppression or from *Sirex* attack, and they therefore maintain a more complete crown cover.

Differences Between Trays at Each Site

The following standard errors (expressed as a percentage of the mean) indicate the variations in the total weights of needles collected in individual trays at each site.

Site	A	B	C	D	E	F	G
S.E. (%)	19.7	3.8	6.5	1.5	9.2	9.6	2.0

Taking a standard error of less than 10% as satisfactory, only at site A has the number of trays been too small to give an adequate estimate of the total needle fall. At this site the regeneration was uneven and some of the randomly placed trays were in open spaces. These trays collected very little litter during the first years of the experiment but with the closing of the tree canopy, litter fall is becoming more evenly distributed and in the year 1956-57 the standard error was reduced to 14.7%. Variations in the weights of "other litter" were slightly greater at all sites.

Seasonal Distribution

The monthly litter falls under Corsican pine at site D and under radiata pine at sites B and C have been plotted in Fig. 1. Most Corsican-pine needles fall in the autumn (March, April, and May). This agrees with the findings of Wright (1956) for the same species in Scotland and those of Chandler (1943) for conifers in general. Radiata pine shows a similar pattern of needle fall but a considerable proportion of the total fall does occur throughout the rest of the year.

As might be expected, the fall of other litter (twigs, etc.) under both species is governed to a large extent by the occurrence of storms, which also have some effect on the needle fall.

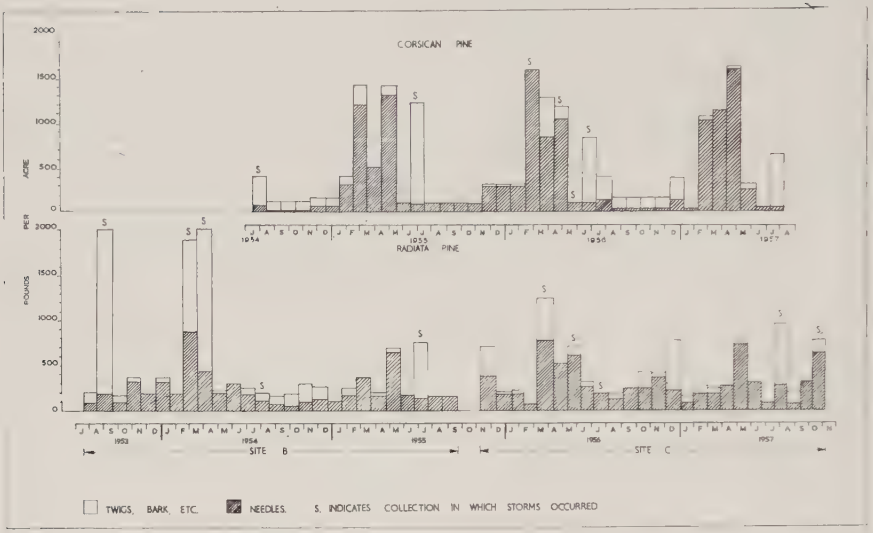

Fig. 1.—Rate of litter fall, determined monthly, beneath radiata and Corsican pines.

In Fig. 2 the mean monthly distribution of litter fall (needles and pollen cones) over four years is given for site A. When the fall of pollen cones in October and November is taken into account, it can be seen that here the needle fall is more evenly distributed throughout the year than is the case with the older trees at sites B and C (Fig. 1). The trees at site A have branches down to ground level which intercept needles falling from the tree crowns. These dead needles tend to hang for a considerable period because there is very little air movement among the trees; over a period of a year the total air movement, 4 ft above the ground, at site A was only about 3% of that at site B. This will have the effect of distributing the fall more evenly throughout the year.

The needle fall under Douglas fir shows no definite seasonal pattern but under larch it is, of course, in late autumn that the main fall occurs. Storms influence the fall of needles and twigs from these two species also.

Chemical Composition

The mean composition of the litter from each site is given in Table 2. For the needles, maximum and minimum figures for monthly samples are included. These mean percentages lie generally within the range of values found in similar studies in other countries.

It has been observed in several studies (see Wright 1956) that the calcium content of needle fall increases from summer to autumn and that levels of nitrogen, potassium, and phosphorus tend to decrease. In the case of the nitrogen content of Corsican-pine needles in New

TABLE 2. CHEMICAL COMPOSITION OF LITTER (per cent of oven-dry weight)
Mean monthly figures for collections during the periods stated. For needles the maximum and minimum figures for monthly samples are given in parentheses.

Type of Litter	Species	Site	Collection Period	Ca	Mg	K	Na	P	N
Needles	Radiata	A	1953-57	0.65 (0.46–1.10)	0.12 (0.09–0.16)	0.31 (0.12–0.42)	0.055 (0.030–0.105)	0.075 (0.055–0.095)	0.80 (0.36–1.00)
Needles	Radiata	B	1953-55	0.54 (0.37–0.83)	0.11 (0.09–0.15)	0.30 (0.09–0.62)	0.105 (0.060 0.175)	0.065 (0.040–0.115)	0.67 (0.46–1.10)
Needles	Radiata	C	1955-57	0.37 (0.26–0.59)	0.09 (0.07–0.11)	0.31 (0.20–0.43)	0.055 (0.035–0.075)	0.090 (0.070–0.110)	0.69 (0.49–0.91)
Needles	Corsican	D	1954-57	0.74 (0.41–0.96)	0.12 (0.08 0.18)	0.32 (0.21–0.52)	0.110 (0.050–0.170)	0.050 (0.035–0.115)	0.51 (0.37–1.08)
Needles	Douglas	E	1954 55	1.05 (0.66–1.40)	0.13 (0.11–0.17)	0.29 (0.15–0.55)	0.055 (0.035–0.085)	0.105 (0.100–0.140)	1.07 (0.82–1.24)
Needles	Douglas	F	1955-57	1.10 (0.71–1.45)	0.13 (0.09–0.18)	0.21 (0.11–0.29)	0.045 (0.025–0.065)	0.125 (0.095–0.140)	0.83 (0.72–1.17)
Needles	Larch	G	1954-57	0.64 (0.22–0.83)	0.13 (0.09–0.17)	0.11 (0.07 0.28)	0.040 (0.025–0.090)	0.080 (0.055–0.160)	0.89 (0.48–2.00)
Twigs, bark, etc.	Radiata	B	1953-55	0.28	0.06	0.11	0.060	0.065	0.44
Twigs, bark, etc.	Radiata	C	1955-57	0.27	0.07	0.10	0.030	0.040	0.47
Twigs, bark, etc.	Corsican	D	1954-57	0.47	0.05	0.05	0.030	0.025	0.36
Twigs, bark, etc.	Douglas	E	1954-55	0.52	0.07	0.11	0.050	0.065	0.48
Twigs, bark, etc.	Douglas	F	1955-57	0.46	0.05	0.05	0.030	0.035	0.48
Twigs, bark, etc.	Larch	G	1954-57	0.53	0.09	0.14	0.050	0.050	0.50

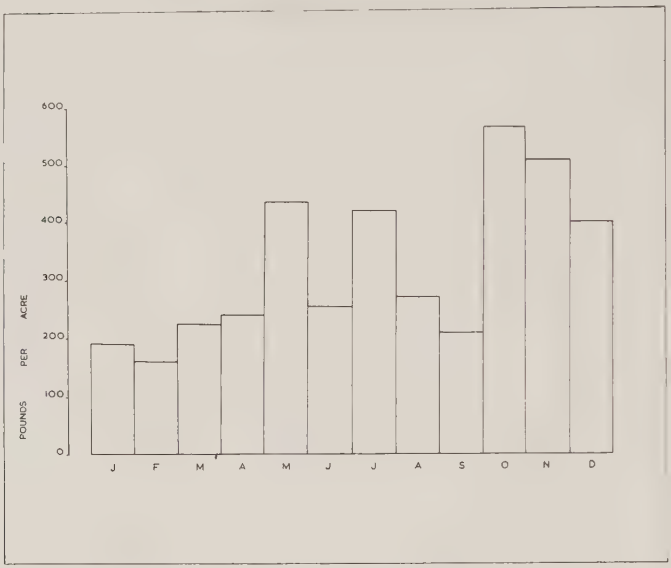

Fig. 2.—Distribution of litter fall throughout the year under young radiata pines (Site A). Four-year means.

Zealand this has been found to be true; needles falling in the autumn have a mean content of 0.41% N while those falling during the remainder of the year contain 0.72% N. In the cases of the other nutrients and species, however, trends in one season have not been repeated in other years.

As could be expected, the highest levels of nutrients are found in the needle portion of the litter but the composition of the 'other litter' is such that it makes a significant contribution towards the total nutrients contained in the litter fall.

Total Annual Nutrient Content

Table 3 records the total weights of nutrients contained in litter fall for different years. These, like the total weights of litter, are higher than those reported for similar species in other countries.

RAINWATER

Chemical Content

From the results of the analysis of rainwater collected beneath radiata pine and Douglas fir, the values in Table 4 have been calculated. It was impossible to exclude all foreign material from the collection funnels, as pollen and pumice dust are carried by the wind in considerable quantities at certain periods. Although all litter found in the collection funnels was removed at frequent intervals, some nutrients in the rainwater will have been leached from this source. However, the amounts added to the rainwater by this means should be

TABLE 3. AIR-DRY WEIGHT AND NUTRIENT CONTENT OF TOTAL LITTER (lb/ac/yr)

Site	Species	Year 19—	Total Litter	Needles Only	Ca	Mg	K	Na	P	N
A	Radiata	53-54	2,600	—	16.9	3.1	8.1	1.4	2.0	20.8
		54-55	3,400	—	22.5	4.2	10.7	1.9	2.7	27.7
		55-56	4,960	—	32.2	6.0	15.4	2.8	3.8	39.7
		56-57	4,880	—	31.7	5.9	15.1	2.7	3.8	39.0
B	Radiata	53-54	9,200	3,720	35.5	7.4	17.2	7.3	5.9	49.1
		54-55	4,060	2,500	17.9	3.7	9.2	3.7	2.7	23.7
C	Radiata	55-56	5,600	3,720	18.9	4.6	13.4	2.6	4.2	34.4
		56-57	5,560	3,860	18.9	4.7	13.7	2.7	4.2	34.6
D	Corsican	54-55	6,400	3,900	40.5	6.0	13.8	4.9	2.6	28.8
		55-56	8,220	5,200	52.6	7.7	18.1	6.5	3.5	37.4
		56-57	6,630	4,680	43.8	6.6	16.0	5.6	2.9	30.8
E	Douglas	54-55	2,590	1,340	20.6	2.6	5.3	1.3	2.2	20.4
F	Douglas	55-56	2,960	2,220	28.3	3.3	5.0	1.2	3.1	22.0
		56-57	2,220	1,670	20.9	2.5	3.8	0.9	2.3	16.5
G	Larch	54-55	3,680	2,220	21.9	4.2	4.4	1.6	2.5	27.1
		55-56	2,940	1,770	17.5	3.4	3.6	1.3	2.0	21.6
		56-57	3,260	1,820	18.8	3.7	4.0	1.5	2.2	23.4

All values are for year ending July except Site C where totals are for year ending November.

no greater than the quantities lost from litter samples between the times of falling and of collection. Hence, by summing the chemical contents of the litter and of the rainwater falling on an area, the total return of nutrients to the soil can be estimated.

As suggested by Miller and Hurst (1957) it seems highly desirable to use trays which collect both litter and rainwater, but the large volumes of rainwater involved present a problem of collection in the field.

Increased rainfall (comparing collection points 2 and 3 in each case) has resulted in decreased amounts of phosphorus and potassium being collected under radiata pine (site C) but increased amounts under Douglas fir (site F). Under the 65–70% crown cover of radiata pine quite a proportion of the rainfall reaches the ground directly without being intercepted by the tree canopy. This results in some points on the ground receiving only rain that has passed through the canopy while others receive varying proportions of direct rain. Collection point 2, site C, being nearer a gap in the canopy than collection point 3, has received more direct rain resulting in a greater volume but a lower mineral content. However, under the 100% crown cover of Douglas fir, an increase in rainfall means an increase in the amount of water that has passed through the tree crown and hence an increase in the phosphorus and potassium collected. The differences in volume and content here are due to the shedding of rain by the tree

TABLE 4. YEARLY TOTALS OF NUTRIENTS IN RAINWATER COLLECTED IN THE OPEN AND BENEATH STANDS OF TREES
(lb/ac)

Site	Year	Collection Point	Location	Rainfall Reaching Ground (in.)	Ca	K	Na	P
B (Radiata pine, Whakarewarewa Forest)	Dec. 54-Dec. 55	1	30 yd from trees	—	2.7	4.5	31.8	0.23
		2	Beneath trees 1.	—	4.0	21.3	68.3	0.51
		3	Beneath trees 2.	—	4.6	24.7	77.2	0.65
C (Radiata pine, Kaingaroa Forest)	Nov. 55-Nov. 56	1	30 yd from trees	73	2.9	4.2	27.5	0.23
		2	Beneath trees 1.	57	2.8	11.9	26.0	0.67
		3	Beneath trees 2.	49	3.4	28.7	30.5	1.91
	Nov. 56-Nov. 57	1	30 yd from trees	46	2.3	2.1	20.5	0.22
		2	Beneath trees 1.	35	2.4	11.1	22.0	0.43
		3	Beneath trees 2.	28	2.7	18.4	24.5	1.31
F (Douglas fir, Kaingaroa Forest)	Apr. 55-Apr. 56	1	20 yd from trees	57	3.9	9.3	36.0	0.55
		2	Beneath trees 1.	21	6.7	22.3	35.5	4.12
		3	Beneath trees 2.	42	5.0	26.2	33.0	6.12
	Apr. 56-Apr. 57	1	20 yd from trees	76	2.8	6.1	30.0	0.24
		2	Beneath trees 1.	31	4.1	20.3	28.5	2.16
		3	Beneath trees 2.	42	4.5	28.0	28.5	3.93

crowns so that points beneath places where two tree crowns meet receive more rain than points under the cover of individual crowns.

The high quantities of sodium found in the rainwater are what might be expected from the presence of cyclic salt (Blakemore 1953) plus dust contamination. It is interesting to note from the figures in Table 4 that only at site B does there seem to be additional sodium washed from the tree crowns of radiata pine.

Here the top soil contains 1.33 me. % of exchangeable sodium compared with 0.34 me. % in the soil at site C (Will unpublished). This higher level of sodium in the soil is also associated with a greater sodium content in the litter (see results for sites B and C in Table 2). The fact that the litter from the younger radiata pine trees at site A contains only half the concentration of sodium found in the litter at site B raises an interesting question as the sites are on the same soil type. Further work is needed on the possible variations in litter composition with the age of trees and with successive crops on the same site before any attempt can be made to answer it.

Seasonal Variation in Content

At all collection points, under both radiata pine and Douglas fir, considerable variations occurred in the quantities of both phosphorus and potassium in the rainwater. To illustrate the variations that occurred, results from collection point 3, site C (radiata pine) and collection point 3, site F (Douglas fir) are shown in Fig. 3.

As the lengths of collection periods varied considerably (depending on the time it took to fill the collection bottles which held approx. 4 in. of rain), the rates of collection of phosphorus and potassium, rather than the total amounts, for each period have been plotted against time. The areas of the rectangles thus indicate the total amounts collected. It will be seen that the amounts collected during periods of heavy rain were small compared with periods of scattered rain, but the rates were similar. This shows that the collection of phosphorus and potassium is not just a function of the amount of rain passing through the tree crown. It may be better to consider Fig. 3 as representing the average rates at which phosphorus and potassium were 'excreted' in the tree crown ready to be dissolved and removed whenever the next fall of rain occurred.

There is a marked seasonal variation in the amount of phosphorus and potassium in rainwater collected under both the radiata pine and the Douglas fir. The quantities collected are low in winter but rise during the summer to a maximum in the autumn. This is probably associated with changes in the metabolic activity of the trees, the autumn maximum being due to the release of nutrients from senile needles which are about to fall.

In the case of potassium the high values recorded in October and November can probably be accounted for by pollen contamination of the collecting funnels, for during these months a yellow coating of pollen was found in all funnels. Radiata-pine pollen has a potassium

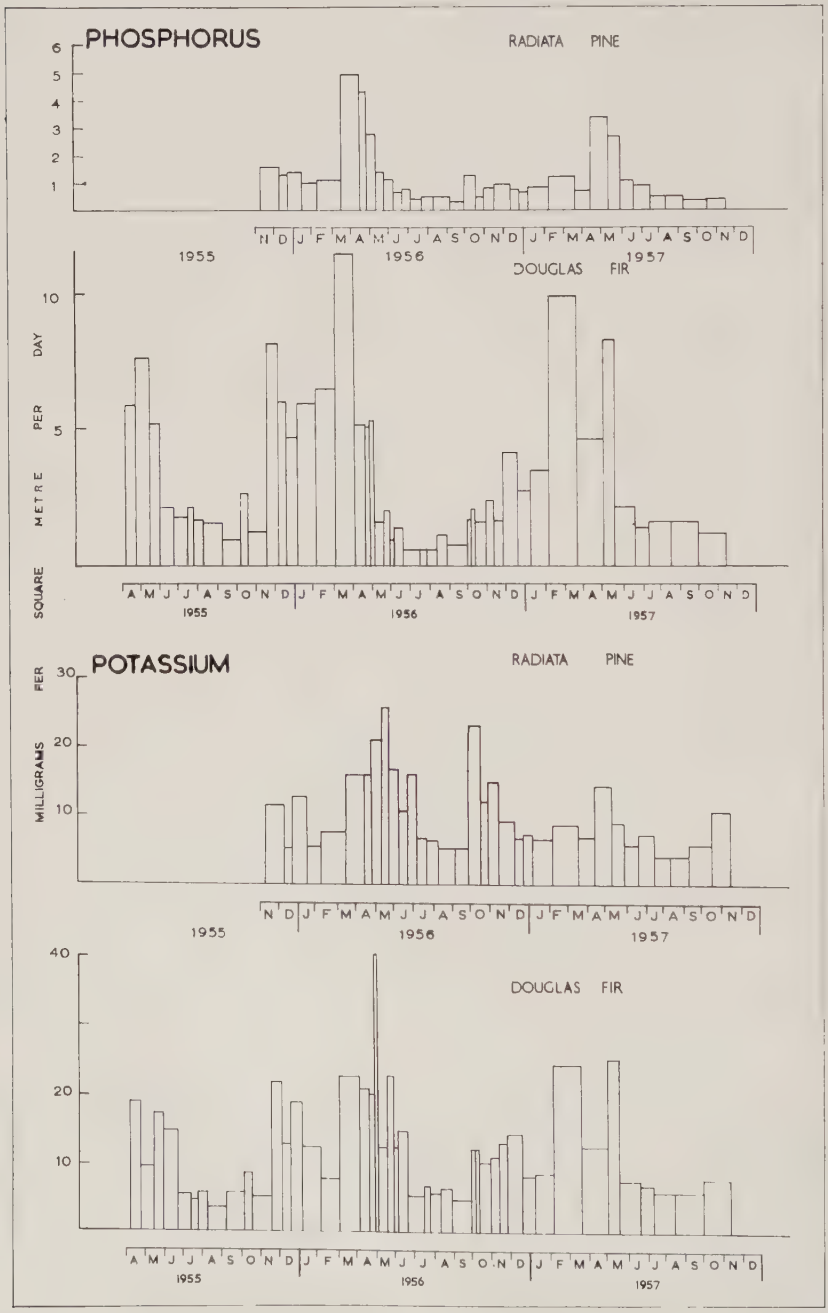
PHOSPHORUS
RADIATA PINE
6
5
4
3
2
1
N D J F M A M J J A S O N D J F M A M J J A S O N D
1955
1956
1957
DOUGLAS FIR
10
5
MILLIGRAMS PER SQUARE METRE PER DAY
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1955
1956
1957
POTASSIUM
RADIATA PINE
30
20
10
MILLIGRAMS PER
N D J F M A M J J A S O N D J F M A M J J A S O N D
1955
1956
1957
40
20
10
DOUGLAS FIR
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1955
1956
1957

Fig. 3.—Seasonal variations in the phosphorus and potassium reaching the ground in rainwater at individual points beneath radiata pine and Douglas fir.

content of about 0.8% of which two-thirds can be extracted by soaking in water for three days.

TOTAL RETURN OF NUTRIENTS TO THE SOIL

From the quantities of nutrients in the litter and the rainwater collected under radiata pine (sites B and C) and Douglas fir (site F), average annual values have been obtained, and these are given diagrammatically in Fig. 4.

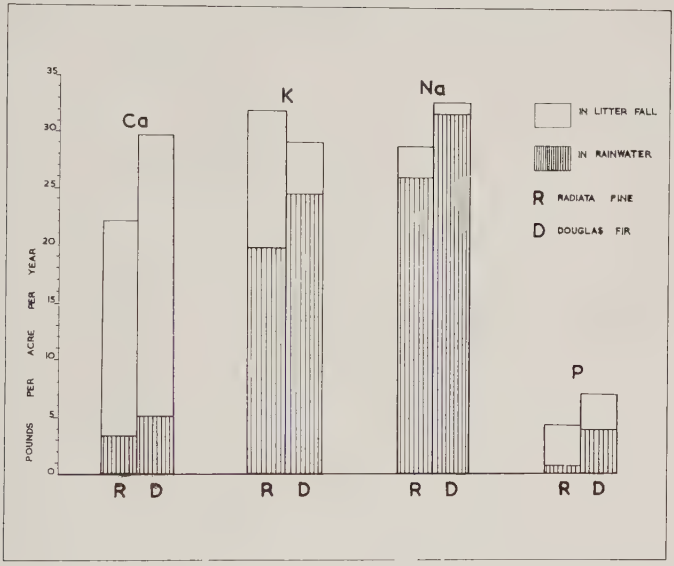

Fig. 4.—Totals of nutrients reaching the soil under radiata pine and Douglas fir.

It must be stressed that the totals in rainwater are only approximate, mainly because of the variation between results from individual collection points. Nevertheless some interesting comparison can be made.

Most of the calcium is contained in the litter but a considerable proportion of the total potassium, sodium, and phosphorus reaches the ground in the rainwater. In the case of potassium and phosphorus most of this has been removed from the tree crowns, but practically all the sodium is in the rainwater before it reaches the tree canopy (see Table 4). The sodium results from site B have not been used, as the sodium content of the soil here has apparently had an abnormal influence in this case.

Tamm (1951) showed that significant amounts of some nutrients are dissolved from tree crowns by rain, but otherwise it has always been assumed that the litter contained most of the nutrients returned to the soil. However, from Fig. 4 it can be seen that, under New

Zealand conditions, at least two-thirds of the potassium reaching the soil under radiata pine and Douglas fir and half the phosphorus under Douglas fir do so in the rainwater. It seems, then, that in the study of tree nutrition, particularly the return of nutrients from the trees to the soil and the availability of these for future uptake, the quantities of nutrients contained in rainwater must be considered. Presumably these nutrients being in a soluble form, will be readily available for uptake by the trees.

Conclusions

Although the collection of litter and rainwater will have to be continued for a number of years to follow changes during the life of a stand of trees, the present results provide an indication of the quantities of litter and nutrients being returned to the soil under exotic conifers in New Zealand.

The main conclusions from the results obtained so far may be summarised as follows:

1. Annual rates of litter fall in New Zealand are higher than those in other countries for which data are available. Average annual weights per acre are of the order of:—5,000 lb for radiata pine, 6,500 lb for Corsican pine, 2,500 lb for Douglas fir, and 3,000 lb for European larch.

2. The nutrient composition of litter in New Zealand is similar to that elsewhere but, as a result of the greater weight of litter fall, the total addition of nutrients to the soil is greater.

3. As reported from other countries, most Corsican-pine needles fall in the autumn, but under radiata pine the seasonal variation is not as great. This is particularly so in stands of younger trees. Needle fall under Douglas fir is fairly evenly distributed throughout the year. As might be expected, storms influence the fall of twigs and branches under all species.

4. Clearly defined seasonal trends in the nutrient composition of litter fall have not been found except in the nitrogen content of Corsican-pine needles, which is low in the autumn.

5. The amounts of potassium and phosphorus reaching the soil in rainwater under radiata pine and Douglas fir are considerable. In a year, the rainwater collected under Douglas fir contains about the same amount of phosphorus and at least twice as much potassium as the litter falling on the same area. Under radiata pine the proportions in the rainwater are smaller but still significant, 60% of the total potassium and 20% of the phosphorus being in the rainwater.

6. The amounts of phosphorus found in rainwater under radiata pine and Douglas fir are at a minimum in the winter and rise to a maximum in the autumn. Potassium follows a similar but less pronounced trend. Pollen contamination of the collecting funnels increased the potassium in October and November.

7. In Whakarewarewa Forest, where the sodium content of the soil is higher than in Kaingaroa Forest, the sodium content of radiata-pine litter from mature trees is also higher and rainwater gains additional sodium as it penetrates the tree crowns.

ACKNOWLEDGEMENTS

The author wishes to thank other members of the Institute staff for their help and co-operation, particularly Miss J. Taylor who was responsible for carrying on these studies while he was absent overseas. The help of the foresters at Kaingaroa Forest is also gratefully acknowledged.

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GERMINATION INDUCED BY EXCISION OF THE ENDOSPERM OF IMMATURE WHEAT GRAINS

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(*Received for publication, 23 April 1959*)

Summary

Excision of the distal eighth of the endosperm of immature wheat grains accelerated and increased their germination. The treatment was effective on very young grains with milk-like endosperm, providing the embryo was well defined.

Use of this method overcomes delays due to the dormancy of newly harvested wheat and also gains the time normally required for the grain to ripen.

Introduction

The use of a growth chamber providing controlled conditions of light intensity, day length, and temperature allows the rapid development of wheat plants; the life cycle of the spring wheat varieties Selkirk and Gabo has been completed in ten weeks at the Crop Research Division, Lincoln. As optimal growth conditions can be maintained artificially in the chamber throughout the year, it is possible to grow a number of generations from a line in a short time. However, it has been found that seeds taken from newly-matured heads may not germinate for several weeks, or may germinate unevenly. The delay caused by this, and the inconvenience of having plants at different growth stages because of uneven germination, made it desirable to overcome these germination problems.

Pugsley (1956) reported that, by cutting off the distal ("brush") end of the wheat grain at the dough stage, complete germination could be obtained within eight to ten days. This method which has the advantage of considerable technical simplicity over embryo culture, was applied to some hybrid wheat progenies at the Crop Research Division, Lincoln, to test its efficiency and to find the earliest stage of development of the wheat grain at which the treatment would be effective. In its normal development, the wheat grain reaches its maximum size in about four weeks after fertilisation and then shrinks with loss of water. As it shrinks there is a gradual change in the colour of the pericarp from green to yellow-brown, and the endosperm thickens and finally hardens. It might be expected that the germination response of seeds to excision would depend on their stage of development.

Methods

Grain was harvested at different stages of maturity. The seeds from each spike were classified into one of nine maturity groups according to the stage of development of the majority of the seeds. The seeds in a spike were mostly of the same developmental stage,

but because of differences in the flowering time of the florets a few seeds were earlier or later than the majority, and there was in consequence some variation in the germination behaviour.

Immediately after harvesting, the distal eighth of the endosperm of the grains was excised with a sharp scalpel, and the grains were placed on moist pads in petri dishes. These were kept at 25°c in darkness for fifteen days, after which they were kept in natural light at approximately the same temperature for a further sixteen days. Non-excised seeds from other heads received the same treatment. The seeds were recorded as germinated when the radicle had burst through the seed coat and was about 1 cm long. The seeds were not surface sterilised, but a drop of toluene was placed at the centre of each pad to reduce the growth of moulds.

The lines of wheat used in the investigations were F1 generations of spring wheat crosses.

The nine classification groups, in order of increasing maturity, were as follows:

1. Seed small, green, pubescent; watery to milk-like endosperm; embryo very small and not well-defined.
2. Approximately three weeks after flowering; seed plump, green; milk-like endosperm; embryo enlarged.
3. Seed very plump, pale green starting to yellow; cream-like endosperm; embryo large.
4. As for 3 but more yellow in colour; embryo large and well defined.
5. Seed very plump, mainly yellow but some pale green colour present; dough-like endosperm.
6. Seed very plump; yellow colour; firm dough-like endosperm.
7. Seed plump, starting to shrink; full ripe yellow-brown colour; firm to hard endosperm.
8. Seed more shrunken than 7; hard endosperm; embryo prominent.
9. Seed apparently fully mature, shrunken; hard endosperm; embryo prominent.

These stages correspond to the scale of Feekes (see Large 1954) as follows:

Stage	Stage of Feekes
1	10.5.4
2, 3, 4	11.1
5, 6	11.2
7, 8	11.3
9	11.4

The material of Pugsley (1956) would have been of Stages 5 or 6.

Results

The effects on germination of excising the distal ends of grains harvested at the different developmental stages are shown in Table 1.

TABLE 1. EFFECT OF ENDOSPERM EXCISION ON GERMINATION OF WHEAT SEEDS AT DIFFERENT STAGES OF DEVELOPMENT

F1 Progeny	Stage of Maturity	No. of Excised Seeds Germinating in Five-day Intervals									No. of Non-excised Seeds Germinating in Five-day Intervals								
		1-5	6-10	11-15	16-20	21-25	26-31	Total	Total No. Tested	Germination Percentage	1-5	6-10	11-15	16-20	21-25	26-31	Total	Total No. Tested	Germination Percentage
Selkirk × Gabo	1							0	14	0									
	3	3	7		1			11	14	79									
	4		7	2	1			10	12	83									
	6	1	6	2	5	1		15	16	94									
	7		1		3			4	4	100									
	8	4	5	2				11	11	100				2			2	10	20
	8	10	2					12	12	100			2	3		2	7	11	64
	9	2	4	4	1			11	11	100						5	5	10	50
Dundee 48 × Aotea[6]	2	8	1	1				10	12	83			1	1		2	4	11	36
	3	2	3	3	1			9	17	53			1		6		7	18	39
	4	1	4	7	2	2		16	17	94			1	6		2	9	17	53
	5		3	9	3			15	15	100			2	2		1	5	14	36
C.I. 12633 × Aotea[4]	1			2				2	23	9									
C.I. 12633 × Hilgendorf[4]	3		9	2				11	14	73									
	4		13	1				14	15	93									
	4	7						7	7	100									
C.I. 12633 × Arawa[4]	5		23	1				24	24	100			4		1		5	6	83
C.I. 12633 × Hilgendorf[5]	6		5					5	5	100									
		38	93	36	17	3		187	243				11	14	7	12	44	97	

Of the excised seeds from the Selkirk × Gabo progeny those showing stage 1 maturity did not germinate. Most of those showing stage 3 to stage 7 maturity germinated within twenty days and many of them did so within ten days. All of the seeds with stage 8 to stage 9 maturity germinated within fifteen to twenty days, with many seeds germinating by the fifth day.

In the Dundee 48 × Aotea[6] backcross progeny, ten of the twelve excised grains showing stage 2 maturity germinated within fifteen days, and high germinations were obtained from the seeds showing stage 4 or 5 maturity. The behaviour of the ear harvested at stage 3, which gave only 53% germination, would appear to be atypical and is not fully understood.

In the C.I. 12633 × Aotea[4] backcross progeny only two of twenty-three seeds showing stage 1 maturity germinated after excision. In the remaining three backcrosses: C.I. 12633 × Hilgendorf[4], C.I. 12633 × Arawa[4], and C.I. 12633 × Hilgendorf[5], the seeds with stage 3 to stage 6 maturity showed high or complete germination within fifteen days.

Of the 187 excised seeds which germinated from all progenies, 70% germinated within ten days of being excised, while all except three of the 187 had germinated within twenty days.

Developmental stages 2, 3, 4, 5, 8, and 9 were represented in the control seeds. Germination in all of these was considerably less than that of the excised seeds from different ears of the same progenies, as can be seen from a comparison of the germination percentages, and in no case was germination complete. Also, no germination had occurred by the tenth day, by which time two thirds of the excised seeds from the same progenies had germinated. There was no suggestion of real differences in behaviour between the six progenies.

TABLE 2. RELATIONSHIP OF GERMINATION RESPONSE TO DEVELOPMENTAL STAGE FOR EXCISED AND NON-EXCISED SEEDS

Developmental Stage	Mean Germination of Excised Seeds %	Mean Germination of Non-excised Seeds %
1	5	—
2	83	36
3	69	39
4	92	53
5	100	50
6	95	—
7	100	—
8	100	43
9	100	50

The relation between germination response and developmental stage for excised and non-excised seeds is summarised in Table 2. In the case of excised seeds, complete or nearly complete germination was obtained from seeds at developmental stages 5 to 9, and the germination of stage 2, 3, and 4 seeds was quite satisfactory. There was very little germina-

tion of seeds showing stage 1 development. The germination of non-excised seeds of stages 2 to 9 showed a similar relation to developmental stage, but at a level which was lower by about 50%.

DISCUSSION

The results show that excision of seeds gave an earlier germination response, a briefer germination-time range, and a more complete germination than occurred in non-excised seeds. Reasonable or complete germination resulted from the treatment of all seeds showing developmental stages 2 to 9. The reason for the germination failure of the stage 1 seeds would appear to be that the embryo was not fully differentiated in them. Percival (1921), in a description of wheat-grain development, stated that the embryo becomes fully differentiated at about the time the grain attains its maximum volume, and contains a milk-like endosperm. This would correspond to stage 2 of the classification used here, in which an increase in embryo size was noted. The only major factor limiting the earliness with which immature grain can be induced to germinate by excision of the endosperm would then appear to be the incomplete development of the embryo itself. It might appear from this that the development of an undifferentiated embryo cannot be completed after the young seed has been removed from the spike.

It is of interest that Rommel (1958) found that the best time for the artificial culture of embryos of unripe cereal seeds was from eighteen to twenty-one days after fertilisation, which age would correspond to stage 2 maturity.

The incomplete germination occurring in seeds from heads classified into developmental stages 2 to 4 was most likely the result of the presence in these heads of some younger seeds with immature embryos. The embryos were not large in these seeds, which showed their general immaturity by retaining their green colour after the treatment instead of changing to a buff or yellow colour as did more mature seeds from the same ears. Retention of the green colour after the treatment was observed in all seeds showing stage 1 maturity.

In conclusion it can be stated that, for practical purposes, seeds which have recently become plump, and in which the embryo is well defined (that is, of stage 2 or 3 maturity), can be excised as described above to give approximately 70% germination within 15 days, whereas less than 40% would germinate within 31 days if they were not excised. Complete germination cannot be expected from heads showing these early stages of maturity and if this is desired of a particular spike it would be better to wait until the seeds have changed from green to yellow and have a dough-like endosperm (stage 5 or later), when excision could be expected to give almost 100% germination within 15 to 20 days, whereas only about 50% of such seeds would germinate within 31 days if they were not excised.

The method described here has the advantage not only of overcoming the delays and wide range of germination time consequent upon the dormancy of newly harvested seed, but also gains the time

normally required for the seed to ripen. This would be of the order of two weeks, and is an important consideration when several generations of wheat are being grown in one year.

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THE INSECT COMPLEX OF SOWN PASTURES IN THE NORTH ISLAND

III. THE DIPTERA AS REVEALED BY SUMMER SWEEP-SAMPLING

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(*Received for publication, 16 April 1959*)

Summary

A sweep-sampling survey carried out during the summer of 1957 revealed 68 species of Diptera in the nine main pasture types found in the North Island. The identity, distribution, and abundance of many of these species are indicated, and their possible economic importance is discussed.

Introduction

During the summer of 1957, a survey of insects associated with pastures in the North Island was carried out. In an earlier paper (Cumber 1958) techniques, coverage, and relevant sampling station details are given, and the insect complex generally as shown by sweep-sampling is analysed and discussed. The information in respect of the Hemiptera taken has already been indicated (Cumber 1959).

The present account gives information in respect of the species of Diptera taken during sweep-sampling which have now been identified by one of us (R.A.H.). The identity of the species, their distribution, and the numbers encountered are shown, and their possible importance in the light of systematic position and known habits is discussed.

The survey involves 113 paddock and 108 adjacent roadside samples each comprising a single sweep from an area of approximately eight square yards.

Distribution maps for 17 of the more commonly encountered species are presented, the presence of a species being indicated by a black dot in contrast to a circle where sampling failed to reveal its presence.

Results

Sub-order **Nematocera**

Fam. Tipulidae (Daddy-long-legs, Crane Flies)

There is a very considerable fauna belonging to the Tipulidae in New Zealand, but little is known of the biology of any of our species.

When tipulids are known to be damaging, it is invariably the larval stage or "leather jacket" which is responsible. Larval habits include the feeding upon decaying vegetation, living roots, mosses, fungi, and

even aquatic worms, and a leaf-mining species is known. It is the species which feed upon the roots of living plants which are of economic importance. Overseas they are often troublesome in pasture and meadow lands, and they are known to attack a great number of crops such as oats, potatoes, mangolds, and turnips. Damage in spring during crop establishment is often important. Spring soil examinations are thus more likely to reveal any damaging species. There is a need for the study of tipulids that damage agricultural crops, and nurseries and gardens in New Zealand.

*D. 15. *Undetermined*

This large species was taken in 4 paddock (8 specimens) and 6 roadside (21 specimens) samples, the localities being Hihitahi, 18.3.57; Ohakune, 18.3.57; Carterton, 25.3.57; Masterton, 25.3.57; Pahiatua, 25.3.57; Palmerston North, Pahiatu Track, 25.3.57; Norsewood, 26.3.57; and Manaia, Taranaki, 3.4.57.

These records indicate that this species is generally distributed in southern portions of the North Island with adults on the wing from mid March to early April. It is possible that the distribution extends further northwards, but being a relatively late-flying species, it was missed in the earlier northern survey. It could be of some economic importance.

D. 59. *Undetermined*

A single specimen of this small species was taken in a paddock sample from Rangipo on 4.3.57.

Fam. Culicidae (Mosquitoes)

The habits of mosquitoes are particularly well known overseas because of their ability to transmit diseases. The habits of the New Zealand species have not received a great deal of attention apart from the work of Graham (1930, 1940). In agriculture they cannot be regarded as important except in their capacity to annoy animals or to transmit animal diseases.

D. 67. *Culex* sp.

A single specimen was taken in a roadside sample from Greytown on 25.3.57.

Fam. Cecidomyiidae (Gall Midges)

A considerable number of species occur in New Zealand, but the systematics of the group is very imperfectly known. The greater part of the type material has been lost, and the identity of the species encountered in the present survey cannot be determined with accuracy until revisions have been made. In view of the economic importance of many species, the case for detailed study of this family in New Zealand is a particularly strong one.

* Undetermined species are located in the collection of the Entomology Division, Palmerston North, under the numbers shown.

Damage is caused by the larval stages which exhibit great diversity of habit. Although zoophagous and saprophagous species are known, the majority are phytophagous, and produce galls in one part or another of the plants. The economically important genera *Dasyneura, Mayetiola* and *Stenodiplosis* occur in New Zealand (Miller 1950). Morrison (1938) describes the severe damage to wheat resulting from attack by the Hessian fly *Mayetiola destructor* Say. in the South Island.

Five species have been recognised during this pasture survey work. Closer studies will probably reveal a large number of species as the adult life in most cases is very short.

D. 14. *Undetermined*

This species was taken in 29 paddock (80 specimens) and 9 roadside (18 specimens) samples, the greatest catch being in a paddock sample from the Eketahuna-Pahiatua district on 25.3.57 which yielded 12 specimens. It is of widespread occurrence in the North Island (Fig. 1). This species was taken in January, 4 samples; February, 8: March, 21; and early April, 5.

D. 27. *Undetermined*

Single specimens of this species were taken in a roadside sample from Wallingford on 26.3.57, and in a paddock sample from Kohinui on 28.3.57.

D. 43. *Undetermined*

This species was taken in 2 paddock (2 specimens) and 4 roadside (9 specimens) samples from Eltham, 24.1.57; Waverley, 24.1.57; Gisborne-Tiniroto, 12.2.57; Eketahuna, 25.3.57; Greytown, 25.3.57; and Kohinui, 28.3.57.

D. 65. *Undetermined*

A single specimen was taken in a roadside sample from Ohakune on 18.3.57.

D. 66. *Undetermined*

A single specimen was taken in a roadside sample from Masterton on 25.3.57.

Fam. MYCETOPHILIDAE (Fungus Gnats)

There have been no detailed studies on the biology of the Mycetophilidae in New Zealand, although there are a great number of species. Most will be dependent upon decaying organic matter or fungus materials for larval development, and for this reason are not considered to be of major importance in agriculture. It is known, however, that in the Sciarinae there are species which damage the roots of potatoes, wheat, grass, cucumbers, etc.

Fig. 1

Fig. 2

Fig. 1.—Distribution map for cecidomyiid. Undetermined. D.14.

Fig. 2.—Distribution map for mycetophilid *Sciara agraria*. D.11.

D. 56. *Mycetophila impuncata* (?) Edw.

This may prove to be another species. *M. impunctata* is described from Ben Lomond, 5,000 ft. The present species was taken at Waverley, 24.1.57: roadside 2 specimens, paddock 4 specimens, and Carterton, 25.3.57, roadside 5 specimens.

D. 45. *Platyura* (near) *campbelli* Tonn.

Single specimens were taken in roadside samples from Waverley, 24.1.57, and Eketahuna-Pahiatua, 25.3.57. *P. campbelli* is described from the Christchurch district.

D. 11. *Sciara agraria* Felt.

Distribution: This cosmopolitan species is recorded by Tonnoir and Edwards (1927) from Utiku, King Country, and Dunedin. In the present survey it was taken in 31 paddock (68 specimens) and 30 roadside (73 specimens) samples, the greatest catch being 14 in a paddock sample from Opotoki on 14.2.57. It is widely distributed in the North Island (Fig. 2).

Habits: These are unknown. It was taken in January, 19 samples; February, 17; March, 21; and early April, 4.

Economic Significance: This species must be regarded with suspicion in view of its consistent appearance in pastures and the importance in agriculture of some species of *Sciara*.

D. 32. *Sciara annulata* Meig.

Distribution: Tonnoir and Edwards (1927) record "Numerous specimens from Ohakune, Governor's Bay, Christchurch, White Rock, Nelson, Akaroa and Kaikoura . . . The North American *S. prolifica* Felt. appears to be the same species, which is probably cosmopolitan." In the present survey it was taken in 11 paddock (12 specimens) and 9 roadside (14 specimens) samples. It is widely distributed in the North Island (Fig. 3).

Habits: No information is available. It was taken in January, 11 samples; February, 2; March, 6; and early April, 1.

Economic Significance: The small numbers encountered make it unlikely that this species, or the three which immediately follow, are of economic importance in pastures.

D. 29. *Sciara* sp.

This species was taken in roadside samples from Te Kuiti, 24.1.57, 1 specimen, and Opotiki-Whakatane, 14.2.57, 2 specimens.

D. 39. *Sciara* sp.

This species was taken in a paddock sample from Opotiki, 14.2.57, 1 specimen, and in roadside samples from Maramarua, 6.3.57, 1; Taihape, 18.3.57, 2: and Eketahuna, 25.3.57, 2.

Fig. 3

Fig. 4

Fig. 3.—Distribution may for mycetophilid *Sciara annulata.* D.32.

Fig. 4.—Distribution map for chironomid. Undetermined. D.18.

Christchurch, Timaru, Charteris Bay, Roxburgh, and Martin's Bay. In the present survey it was taken in 34 paddock (182 specimens) and 21 roadside (82 specimens) samples, the greatest catch being 32 in a paddock sample from Alton taken on 24.1.57. It occurs widely in areas south of Auckland (Fig. 14).

Habits: This species was taken in January, 10 samples; February, 22; March, 21; and early April, 2.

Economic Significance: This species is present in moderate numbers over a wide area, and because of its systematic position, must be regarded with some suspicion.

D. 28. *Scatella nitidithorax* Mall.

Harrison (1959) records this species from Auckland, Waitakere Ranges, National Park, and Nelson. In the present survey a single specimen was taken in a paddock sample from Ohaewai on 19.1.57.

Fam. Chloropidae

Flies belonging to the Chloropidae are usually found in areas of miscellaneous herbage such as roadsides and meadows. For the most part the larvae are phytophagous, and the family includes important pests of monocotyledonous crops, such as the fruit fly, which in Europe are troublesome to cereals and grasses. A few species with larvae predaceous on aphids are known. As with the Ephydridae, their real importance in pastures cannot be determined, without closer studies.

D. 58. *Gaurax mesopleuralis* (Beck.)

A single specimen was taken in a paddock sample from Opotiki-Whakatane on 14.2.57.

D. 26. *Melanum neozelandicum* Mall.

This species was taken in a paddock sample from Coromandel, 6.3.57, 2 specimens, and in roadside samples from Hunterville, 22.3.57, 1, and Inglewood, 2.4.57, 2.

D. 12. *Oscinosoma badia* (Hutt.)

Distribution: This species was described by Hutton (1900) from material collected at Queenstown. In the present survey it was taken in 23 paddock (94 specimens) and 19 roadside (316 specimens) samples, the greatest catch being in a roadside sample from Waverley on 24.1.57 which contained 180 specimens. This species is of common and widespread occurrence in the North Island (Fig. 15).

Habits: Nothing is known of the habits of this species. It was taken in January, 20 samples; February, 14; March, 6; and early April, 2.

Economic Significance: This species should be viewed with some suspicion because of its wide distribution and the high populations occasionally found.

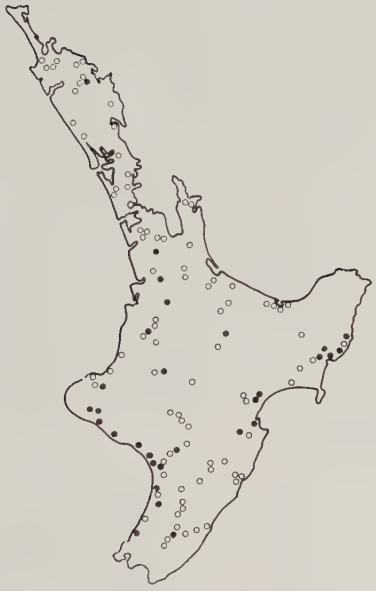

Fig. 15

Fig. 16

Fig. 15.—Distribution map for chloropid. *Oscinosoma badia*. D.12.

Fig. 16.—Distribution map for calliphorid. *Sarcophaga milleri*. D.1.

SCHIZOPHORA-CALYPTERAE

Fam. CALLIPHORIDAE

The larvae of the Calliphoridae according to Imms (1957), "may be saprophagous, or flesh feeders, or parasites of various arthropods, the parasitic habit being less developed in this family than in the Tachinidae." The family is important in medical and veterinary fields, representative species being responsible for conditions such as myiasis in man and blowfly strike in sheep.

D. 1. *Sarcophaga milleri* J. et T.

Distribution: Hutton (1900) gives a description of *Sarcophaga impatiens* Walk., indicating that he considers that it has been introduced from Australia, and recording it from Whangarei and Christchurch. This almost certainly refers to the species which is now generally known as *S. milleri* and which is of widespread occurrence in New Zealand. In the present survey it was taken in 86 paddock (411 specimens) and 87 roadside (841 specimens) samples, the greatest catch being in a roadside sample from Woodhill on 23.1.57 which contained 76 specimens. Fig. 16 indicates its widespread occurrence in the North Island.

Habits: This species is known to breed freely in animal manure hence its universal association with farms carrying stock. The pupae

Sub-order **CYCLORRHAPHA**

ASCHIZA

Fam. LONCHOPTERIDAE

The larvae of the Lonchopteridae are found amongst decaying organic matter. The family is not considered to be important in agriculture.

D. 6. *Lonchoptera dubia* Curran

Distribution: This is a cosmopolitan species, and in this survey was found to be distributed throughout the North Island (Fig. 5). It was taken in 59 paddock (361 specimens) and 24 roadside (108 specimens) samples, the greatest catch being 19 in a paddock sample from Masterton taken on 25.3.57.

Habits: This species was taken in January, 23 samples; February, 19; March, 36; and early April, 5; indicating a series of overlapping generations.

Economic Significance: It is not likely to prove of importance in pastures as its systematic position indicates that the larvae are probably associated with decaying vegetable matter.

Fig. 5

Fig. 6

Fig. 5.—Distribution map for lonchopterid. *Lonchoptera dubia*. D.6.

Fig. 6.—Distribution map for phorid. *Megaselia* sp. D.7.

Fam. Phoridae

The Phoridae have varied habits, but they are usually associated with decaying vegetable materials, and for this reason are not usually considered to be of importance in agriculture. There are some parasitic species however, as indicated by Hudson (1891), who records Lepidoptera, Coleoptera, and Hymenoptera as hosts.

D.7. *Megaselia* sp.

Distribution: This species was taken in 47 paddock (170 specimens) and 31 roadside (113 specimens) samples, the greatest catch being 28 in a roadside sample from Waverley on 24.1.57. Fig. 6 indicates its distribution and shows that it is widespread in the North Island.

Habits and Economic Significance: It was taken in January, 12 samples; February, 17; March, 42; and early April, 7. It is unlikely to be of economic importance in pastures.

D. 13. *Undetermined*

This species occurred in 4 paddock (14 specimens) and 10 roadside (14 specimens) samples taken at Wellsford, 22.1.57; Inglewood, 24.1.57; Sanson, 7.2.57; Coromandel, 6.3.57; Maramarua, 6.3.57; Pukekohe, 7.3.57; Tuakau, 7.3.57; Mangaweka, 18.3.57; Eketahuna-Pahiatua, 25.3.57; Masterton, 25.3.57; Porangahau, 26.3.57; and Wallingford, 26.3.57.

Fam. Syrphidae (Hover Flies)

The larval habits of the Syrphidae are extremely varied, for phytophagous, saprophagous, and zoophagous species are known. Their biology has been studied in detail by many workers. Only a few species are known to be harmful in agriculture. The predaceous larvae of some must be considered as beneficial insects for they are responsible for a measure of aphid and coccid control.

D. 46. *Eristalis tenax* Linn.

Distribution: This cosmopolitan species is found throughout New Zealand. In the present survey a single specimen was taken in a roadside sample from Pahiatua on 25.3.57. It is a wary species when any movement occurs such as happens when sweep-netting is being carried out.

Habits: The larval stage is the well known "rat-tailed" larva which occurs in stagnant water, ponds, etc., which are rich in organic matter (Miller 1918).

Economic Significance: It is not generally considered important in agriculture. It may, however, in some instances, prove to be an important pollinating agent. The fly is often confused with the honeybee, and its preference for sunny sheltered positions may cause concern at times.

D.21. *Melanostoma fasciatum* Macq.

Distribution: This species was found to be distributed throughout the North Island (Fig. 7). It was taken in 33 paddock (102 specimens) and 46 roadside (140 specimens) samples, the greatest catch being in the case of a roadside sample from Bulls on 30.1.57 which contained 14 adults. Miller (1921) records it from "throughout New Zealand, from spring to autumn."

Habits: According to Miller "The female deposits her yellowish eggs in pairs or sometimes singly upon plants infested with aphids or lepidopterous larvae . . . large numbers of aphids and larvae of the diamond-back moth (*Plutella maculipennis*) are destroyed by this syrphid." This species is thus an important biological control agent.

In the present survey, adults were taken in January, 40 samples; February, 18; March, 17; and early April, 4.

Economic Significance: This is to be regarded as a highly beneficial species.

SCHIZOPHORA-ACALYPTERAE

Fam. TRYPETIDAE (Fruit Flies)

The biology of many species of fruit flies is well known for some are among the most important pests of fruit. Larvae are phytophagous and associated with fruits, flowerheads, leaf and stem mines, and galls.

Fig. 7

Fig. 8

Fig. 7.—Distribution map for syrphid *Melanostoma fasciatum*. D.21.

Fig. 8.—Distribution map for agromyzid. *Cerodontha denticornis*. D.24.

D. 44. *Trypanea alboapicata* Mall.

A single specimen was taken in a paddock sample from Eketahuna-Pahiatua on 25.3.57. This species was described by Malloch (1931) from specimens taken at Cass and Nelson.

Fam. AGROMYZIDAE

This family is of considerable economic importance for the larvae of the majority of species are leaf miners. This biology of many overseas species is well known.

D. 52. *Cerodontha angustipennis* Harr.

This species was taken in 5 paddock (21 specimens) and 2 roadside (4 specimens) samples, the greatest catch being in a paddock sample from Himatangi (30.1.57) which yielded 13 specimens. Other localities were Alton, 24.1.57; Eltham, 24.1.57; Bulls, 30.1.57; Whangaehu, 30.1.57; and Paekakariki, 31.1.57. The habits of this species, which was described by Harrison (1959), are not known. It is apparently an early species, and although numbers taken are small, it cannot be dismissed as unimportant.

D. 24. *Cerodontha denticornis* (Panz.) (Wheat Sheath Miner)

Distribution: This cosmopolitan species is distributed throughout New Zealand. In the present survey it was perhaps the commonest insect swept from pastures, being taken in 109 paddock (5,614 specimens) and 82 roadside (1,266 specimens) samples. The greatest catch was in a paddock sample from Waverley on 24.1.57, which yielded 720 specimens. The distribution encountered is shown in Fig. 8.

Habits: Information on this species in New Zealand is given by Morrison (1938) and Hamilton (1947). In addition to attacking wheat, oats, and barley, it is also known to be a pest of maize, ryegrass, timothy, and other grasses. Adults emerging from overwintering pupae lay eggs in the leaves. The larvae produce leaf mines, and later damage the sheaths and stems, this being reflected in a whitening of seed-heads. There are several overlapping generations each year. In the present survey, adults were taken in January, 69 samples; February, 41; March, 76; and early April, 5.

Economic Significance: No great importance has been attached to its attacks on barley and wheat in New Zealand, and the damage to ryegrass has not been reported as severe. However, a closer study of this species may reveal that it is far more damaging than has hitherto been suspected, as the numbers taken from pastures are very high indeed.

D. 16. *Phytomyza atricornis* Meig. (Ragwort Leaf Miner)

Distribution: This is a cosmopolitan species. The distribution found in the present survey (Fig. 9) indicates that it is of widespread occurrence in the North Island. It was taken in 30 paddock (137 specimens)

and 16 roadside (46 specimens) samples, the greatest catch of 17 being recorded from a paddock sample taken at Alton on 24.1.57.

Habits: The life-history in New Zealand has been studied by Kelsey (1937) who indicates that this typical leaf-mining species may have as many as 15 generations a year. Wise (1953) lists the following host plants: cineraria, chrysanthemum, marigold, pea, dahlia, sow thistle, dandelion, nettle, capeweed, ragwort, groundsel, and Scotch thistle. In the present survey it was taken in January, 24 samples; February, 4; March, 16; and early April, 2.

Economic Significance: In the light of present knowledge this species is associated only with pasture weeds, and in this capacity must be regarded as a beneficial species.

Fig. 9

Fig. 10

Fig. 9.—Distribution map for agromyzid *Phytomyza atricornis*. D.16.

Fig. 10.—Distribution map for sepsid. *Lasionemapoda hirsuta*. D.5.

Fam. SEPSIDAE

This family is of little economic importance. The larvae are saprophagous and often found in dung. The family was first recorded as being present in New Zealand by Harrison (1959).

D. 5. *Lasionemapoda hirsuta* (de Meij.)

Distribution: This is a cosmopolitan species. In the present survey it was taken in 19 paddock (107 specimens) and 14 roadside (34 specimens) samples, the greatest catch being 27 in a paddock sample from

Victoria Valley, Kaitaia, on 16.1.57. The distribution shown in Fig. 10 indicates that this species may be a relatively recent arrival from abroad with Auckland as point of entry, and that it is in process of reaching the more southern portions of the North Island.

Habits and Economic Significance: It was taken in January, 15 samples; February, 10; and March, 8. It is not considered to be of economic importance.

Fam. Sapromyzidae (Lauxaniidae)

The Sapromyzidae are regarded as being of little economic importance as the larvae are mainly scavengers feeding upon decaying organic matter. Marchal (1897) records a species which damages the leaves of clover.

D. 36. *Poecilohetaerella bilineata* (Hutt.)

Single specimens of this species were taken in roadside samples from Tutira, 11.2.57, and Taihape, 18.3.57.

Fam. Drosophilidae

For the greater part the flies of this family breed in decaying or fermenting fruit and sap, etc., although leaf-mining and predaceous larval forms are known. They are not important in pastures.

D. 34. *Scaptomyza fuscitarsis* Harr.

This species has been described recently by Harrison (1959). In the present survey it was taken in 7 paddock (10 specimens) and 7 roadside (9 specimens) samples, from Te Awamutu, 23.1.57; Mokau, 24.1.57; Norsewood, 11.2.57; Tutira, 11.2.57; Gosborne-Tiniroto, 12.2.57; Gisborne, 13.2.57; Okere Falls, 4.3.57; Taupo-Rotorua, 4.3.57; Mangaweka, 18.3.57; Ohakune, 18.3.57; Eketahuna-Pahiatua, 25.3.57; Masterton, 25.3.57; and Kohinui, 28.3.57.

Fam. Sphaeroceridae (Borboridae)

These flies for the most part breed in decaying organic matter or excrement, and are not considered to be important in agriculture.

D. 20. *Leptocera thomasi* Harr.

This species has been recently described by Harrison (1959). In the present survey it was taken in 20 paddock (37 specimens) and 10 roadside (16 specimens) samples. The distribution met is shown in Fig. 11, which indicates that the species is widespread in the North Island. It was taken in January, 7 samples; February, 9; and March, 4. It is not important in pastures.

Fam. Ephydridae

The flies belonging to this family are generally associated with marshy places and damp meadows. For the most part the larvae are

Fig. 11

Fig. 12

Fig. 11.—Distribution map for sphaerocerid. *Leptocera thomasi*. D.20.

Fig. 12.—Distribution map for ephydrid. *Hydrellia enderbii*. D.8.

phytophagous, although a few species are parasitic on eggs of spiders. Their precise importance in wetter pastures is difficult to gauge without detailed studies of the species commonly found.

D. 8. *Hydrellia enderbii* (?) (Hutt.)

Distribution: This species is described from Enderby Island in the Auckland Islands group, but it is also known from Waitakere Ranges, Palmerston North, Trentham, Kaikoura, Christchurch, Arthur's Pass, Otira, Otago Peninsula, Dunedin, Martin's Bay, and Chatham Islands (Harrison 1959). In the present survey it was taken in 13 paddock (177 specimens) and 4 roadside (44 specimens) samples (Fig. 12), the greatest catch being in a paddock sample from Waverley on 24.1.57 which yielded 136 individuals. It is seen to be widely distributed in central regions of the North Island.

Habits: This species was taken in January, 12 samples; February, 3; and March, 2; indicating that it is probably an early species.

Economic Significance: It may prove to be of some economic importance in pastures.

D. 23. *Hydrellia tritici* Coq.

Distribution: This is a cosmopolitan species. Harrison (1959) records it from Whangarei, Little Barrier Island, Auckland, Waitakere

Ranges, Miranda, Wairakei, National Park, Nelson, Waiho, Reefton, Kaikoura, Christchurch, and McKerrow. In the present survey it was taken in 92 paddock (3,938 specimens) and 43 roadside (574 specimens) samples, the greatest catch, 330, being in a paddock sample from Waverley on 24.1.57. It is seen (Fig. 13) that this species is of widespread occurrence in the North Island.

Habits: These have not been studied in New Zealand. It was taken in January, 43 samples; February, 33; March, 54; and early April, 5.

Economic Significance: This species warrants closer study. It is highly probable that it causes some damage to pastures as its phytophagous larval habits in the Gramineae are well known, and it is commonly present in very considerable numbers in our pastures.

Fig. 13

Fig. 14

Fig. 13.—Distribution map for ephydrid. *Hydrellia tritici.* D.23.

Fig. 14.—Distribution map for ephydrid. *Psilopa metallica.* D.21.

D. 10. *Hydrellia velutinifrons* T. et M.

Tonnoir and Malloch (1926) record this species from Christchurch, Kaikoura, and Otira. In the present survey it was taken in paddock samples from Ruakaka, 21.1.57, 2 specimens, and Dargaville, 22.1.57, 9. It would not appear to be of importance in pastures.

D. 21. *Psilopa metallica* (Hutt.)

Distribution: Hutton (1900) described this species from Christchurch. Harrison (1959) records it from Palmerston North, Nelson,

Christchurch, Timaru, Charteris Bay, Roxburgh, and Martin's Bay. In the present survey it was taken in 34 paddock (182 specimens) and 21 roadside (82 specimens) samples, the greatest catch being 32 in a paddock sample from Alton taken on 24.1.57. It occurs widely in areas south of Auckland (Fig. 14).

Habits: This species was taken in January, 10 samples; February, 22; March, 21; and early April, 2.

Economic Significance: This species is present in moderate numbers over a wide area, and because of its systematic position, must be regarded with some suspicion.

D. 28. *Scatella nitidithorax* Mall.

Harrison (1959) records this species from Auckland, Waitakere Ranges, National Park, and Nelson. In the present survey a single specimen was taken in a paddock sample from Ohaewai on 19.1.57.

Fam. Chloropidae

Flies belonging to the Chloropidae are usually found in areas of miscellaneous herbage such as roadsides and meadows. For the most part the larvae are phytophagous, and the family includes important pests of monocotyledonous crops, such as the fruit fly, which in Europe are troublesome to cereals and grasses. A few species with larvae predaceous on aphids are known. As with the Ephydridae, their real importance in pastures cannot be determined, without closer studies.

D. 58. *Gaurax mesopleuralis* (Beck.)

A single specimen was taken in a paddock sample from Opotiki-Whakatane on 14.2.57.

D. 26. *Melanum neozelandicum* Mall.

This species was taken in a paddock sample from Coromandel, 6.3.57, 2 specimens, and in roadside samples from Hunterville, 22.3.57, 1, and Inglewood, 2.4.57, 2.

D. 12. *Oscinosoma badia* (Hutt.)

Distribution: This species was described by Hutton (1900) from material collected at Queenstown. In the present survey it was taken in 23 paddock (94 specimens) and 19 roadside (316 specimens) samples, the greatest catch being in a roadside sample from Waverley on 24.1.57 which contained 180 specimens. This species is of common and widespread occurrence in the North Island (Fig. 15).

Habits: Nothing is known of the habits of this species. It was taken in January, 20 samples; February, 14; March, 6; and early April, 2.

Economic Significance: This species should be viewed with some suspicion because of its wide distribution and the high populations occasionally found.

Fig. 15

Fig. 16

Fig. 15.—Distribution map for chloropid. *Oscinosoma badia*.. D.12.

Fig. 16.—Distribution map for calliphorid. *Sarcophaga milleri*. D.1.

SCHIZOPHORA-CALYPTERAE

Fam. CALLIPHORIDAE

The larvae of the Calliphoridae according to Imms (1957), "may be saprophagous, or flesh feeders, or parasites of various arthropods, the parasitic habit being less developed in this family than in the Tachinidae." The family is important in medical and veterinary fields, representative species being responsible for conditions such as myiasis in man and blowfly strike in sheep.

D. 1. *Sarcophaga milleri* J. et T.

Distribution: Hutton (1900) gives a description of *Sarcophaga impatiens* Walk., indicating that he considers that it has been introduced from Australia, and recording it from Whangarei and Christchurch. This almost certainly refers to the species which is now generally known as *S. milleri* and which is of widespread occurrence in New Zealand. In the present survey it was taken in 86 paddock (411 specimens) and 87 roadside (841 specimens) samples, the greatest catch being in a roadside sample from Woodhill on 23.1.57 which contained 76 specimens. Fig. 16 indicates its widespread occurrence in the North Island.

Habits: This species is known to breed freely in animal manure hence its universal association with farms carrying stock. The pupae

may be recovered in great numbers from the soil beneath dung pats, etc. The flies search out sweet juices, honey dew, and fermenting fluids. They are commonly found feeding upon the sticky secretions which occur on the seed heads of paspalum. Adults were taken in January, 57 samples; February, 43; March, 67; and early April, 6.

Economic Significance: This species could be important in the veterinary field if it can be shown to be responsible for transmission of intestinal diseases through contamination of fodder. There is also the possibility that it has a nuisance value in settling on stock in association with biting species such as *Stomoxys*.

Fam. Tachinidae

The Tachinidae are essentially parasites of other insects, mainly Coleoptera, Hemiptera, and Lepidoptera, or occasionally other arthropods. Any effect upon agriculture is likely to be a beneficial one.

D. 61. *Engycera politiventris* Mall.

This species was described by Malloch (1939) from specimens taken at Purakanui, Dun Mt., Barewood, Tahunanui, and Roxburgh. In the present survey single specimens were taken from roadside samples at Hihitahi, 18.3.57, and Eketahuna-Pahiatua, 25.3.57. The host relationships of the species are not known.

Fam. Muscidae

The larvae of the Muscidae show considerable diversity of habit. Some are phytophagous and serious pests, others are saprophagous, and zoophagous species are also known. In agriculture, important pests of brassicas, cereals, and beet are well known in Europe. In the medical and veterinary fields their importance is exemplified in the tse-tse flies (*Glossina*) and the biting stable flies (*Stomoxys*).

D. 3. *Hylemyia cana* (?) (Macq.)

Distribution: This species was taken in 8 paddock (150 specimens) and 5 roadside (13 specimens) samples, the greatest catch being from a paddock sample taken at Napier on 11.2.57 which yielded 126 specimens. Fig. 17 shows that it occurs at widely scattered localities in the North Island.

Habits: No information on hosts is available. It was taken in January, 2 samples; February, 8; March, 1: and early April, 1.

Economic Significance: It is probably not important in pastures, although the genus contains known important agricultural pests.

D. 4. *Hylemyia deceptiva* Mall.

Single specimens were taken from a paddock sample at Tutira, 11.2.57, and from roadside samples at Horotiu, 23.1.57, and Gisborne, 13.2.57.

D. 62. *Stomoxys calcitrans* (Linn.) (Blood-sucking Stable Fly)

Distribution: This cosmopolitan species has been established in New

Zealand since the middle of last century (Miller 1939). In the present survey it was taken once only, in a roadside sample from Alton on 24.1.57 which yielded 2 specimens. However, the species is known to be widespread in New Zealand, and particularly prevalent in some North Island districts during the warmer summer months.

Fig. 17.—Distribution map for muscid. *Hylemyia cana* (?). D.3.

Habits: The biting habits of this blood-sucking fly are well known. It will breed freely in compost comprising lawn clippings, and for this reason may be troublesome even in town areas. Apart from its nuisance value both to man and stock, it is a proven vector of serious diseases. According to Roberts (1952) the main breeding sites are mixtures of straw and manure, and rotting vegetation.

Economic Significance: Recent work by Bruce and Decker (1958) and Cheng (1958) provide illuminating evidence on the losses due to reduced milk and beef yields where this fly is abundant. A relatively small number of flies can be responsible for a considerable degree of nuisance. This is an elusive species which rests on walls, posts, and trees, and hence was not taken in numbers during the present survey. It is of considerable economic importance in New Zealand and calls for basic biological studies as a prelude to establishing control measures.

In addition to the above species there are a further 15 which have as yet not been placed. They are for the most part present in small numbers, and unless they prove to be recent introductions are not expected to be of any great importance in pastures.

Discussion

In this account of the Diptera associated with pastures in the North Island, it has been necessary, because of our imperfect knowledge of many of the families in New Zealand, to refer to species in some cases by number only. It is felt that this practice is fully justified in that it allows a balanced picture of the insect fauna to be presented. As further identifications are effected it will be desirable, from time to time, to publish supplementary identification lists.

The families which particularly require revisions are the Tipulidae, Chironomidae, Ceratopogonidae, and Cecidomyiidae. There are economic grounds for desiring further knowledge of the Tipulidae and Ceratopogonidae. The former will doubtless prove to be important in pastures and gardens in some parts of New Zealand, and the latter could be important in the veterinary field. The Chironomidae are regarded as being the least important of these four families, although they too have possible economic implications in the fields of water pollution and allergy.

It is the Cecidomyiidae, however, which most urgently requires attention. There is a considerable New Zealand fauna, and the majority of the type specimens have been lost. Important cosmopolitan species are known to be present, and damaging species such as occur on *Phormium* (Cumber 1954) are as yet unidentified.

Turning now to those families in which the systematics are better known in this country and which are certain to be damaging to pastures in some degree, it is the Agromyzidae, Ephydridae, and Chloropidae which must be regarded as most important. These families have been indicated as important in the works of Balachowsky and Mesnil (1935), Osborn (1939), and Ricou (1957, 1958). In the Mycetophilidae, the Sciarinae may prove to have some damaging representatives.

This survey has indicated the desirability for detailed studies of the Cecidomyiidae, Agromyzidae, Ephyridae, and Chloropidae in pastures. The larvae of these families are for the most part phytophagous, and considerable populations occur.

Many of the species present are doubtless controlled in some measure by hymenopterous agents. It seems probable that the widespread use of insecticides applied to pastures primarily to effect a control of Coleoptera, notably grass-grub species, is also going to have an effect upon these phytophagous species and the parasites which help control them. A knowledge of these phytophagous species is one important prerequisite to intelligent appraisal of the effects of applying such fertiliser-insecticide products to our pastures.

Acknowledgements

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THE INSECT COMPLEX OF SOWN PASTURES IN THE NORTH ISLAND

IV. THE COLEOPTERA AS REVEALED BY SUMMER SWEEP-SAMPLING

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(*Received for publication, 16 April 1959*)

Summary

A sweep-sampling survey during the summer of 1957 revealed 32 species of Coleoptera in the 9 main pasture types occurring in the North Island. The identity, distribution, and abundance of these species are indicated, and their possible economic importance is discussed .

Introduction

During the summer of 1957, a survey of insects associated with pastures in the North Island was carried out. In an earlier paper (Cumber 1958) techniques, coverage, and relevant sampling-station details are given, and the insect complex generally as shown by sweep-sampling is analysed and discussed. The information in respect of the Hemiptera (Cumber 1959) and Diptera (Cumber and Harrison 1959) has already been indicated.

In the present account the Coleoptera which were taken are discussed with regard to the identity of the species, their distribution, numbers encountered, and possible importance in the light of their systematic position and known habits.

The survey involves 113 paddock and 108 adjacent roadside samples each comprising a single sweep from an area of approximately 8 square yards.

Distribution maps for the 3 more-commonly encountered species are presented, the presence of a species being indicated by a black dot, in contrast to a circle where sampling failed to reveal its presence.

Results

Suborder **Adephaga**

Fam. Cicindelidae (Tiger Beetles)

Insects belonging to this family prey on other insects in both larval and adult stages, and are commonly found in localities where the soil is friable or sandy.

Co. 18. *Cicindela tuberculata* F.

This is the common tiger beetle which occurs throughout the North Island. It is an extremely elusive species which no doubt

accounts for its occurrence in only a single sample, that from a paddock taken at Maraekakaho on 11.2.57 which yielded one specimen.

Because of its predaceous habits this species must be regarded as a beneficial one, although its contribution to pastures is probably small.

Fam. Carabidae (Ground Beetles)

The majority of species in this family live in the ground, in rotting wood, under stones, logs, bark, etc. For the greater part both larvae and adults are carnivorous, although a few are known to damage fruits and seeds.

Co. 32. *Hypharpax antarcticus* (Cast.)

A single specimen was taken in a paddock sample from Okere on 4.3.57. The species was originally described from Dunedin. Broun (1880) records it from Auckland. It is unlikely to be of importance in pastures, although, like the preceding species, it may have a minor beneficial effect.

Suborder **Polyphaga**

Fam. Staphylinidae (Rove Beetles)

Many members of this family are predaceous, but the majority live on decaying vegetable matter and are to be found near dung, rotting vegetation, dead animals, etc.

Co. 14. *Atheta* sp.

This species was taken in 10 paddock (12 specimens) and 3 roadside (3 specimens) samples from: Puketona (18.1.57), Ohaewai (19.1.57), Warkworth (22.1.57), Kai Iwi (24.1.57), Waverley (24.1.57), Norsewood (11.2.57), Tutira (11.2.57), Gisborne (13.2.57), Opotiki-Whakatane (14.2.57), Taihape (18.3.57), and Masterton (25.3.57), indicating that it is of widespread occurrence in the North Island.

*Co. 15. *Undetermined*

A single specimen was taken in a paddock sample from Foxton on 4.4.57.

Co. 35. *Astenus* sp.

A single specimen was taken in a paddock sample from Hunterville on 27.3.57.

The habits of the three above species of staphylinids are not known, so their possible importance in pastures cannot be indicated. If they prove to be predaceous, then they may be beneficial.

Fam. Helodidae

Imms (1957) states that members of this family "are found near water in which the larvae live."

* Undetermined species are located in the collection of the Entomology Division Palmerston North, under the numbers shown.

Co. 8. *Cyphon* sp.

A single specimen was taken in a roadside sample from Kaitaia on 16.1.57.

Fam. ELATERIDAE (Click Beetles)

The majority of the species in this family are root feeders in their larval or "wireworm" stages, although wood-boring and zoophagous species are known. In agriculture they may cause very considerable damage, especially to cereals and grasses.

Co. 33. *Lacon variabilis* Cand.

This introduced species is recorded from New Zealand by Hudson (1923). It is probably widespread in the country, but there are no records of any significant build up in pastures. A single specimen was taken in a paddock sample from Masterton on 25.3.57. The adult is probably nocturnal, which would account for the low numbers taken during sweep-sampling.

Fam. CRYPTOPHAGIDAE

Insects belonging to this family are mainly fungus feeders, and are generally considered as unimportant in agriculture.

Co. 26. *Micrambina helmsi* Reitt.

A single specimen was taken in a roadside sample from Kai Iwi on 24.1.57.

Fam. CORYLOPHIDAE

Representatives of this family are minute insects and are usually associated with decaying wood or vegetation. They are not considered as being of importance in agriculture.

Co. 4. *Sericoderus* sp.

This species was taken in 6 paddock (11 specimens) and 7 roadside (7 specimens) samples, from Alton (24.1.57), Tutira (11.2.57), Wairoa (12.2.57), Opotiki (14.2.57), Okere (4.3.57), Te Matai (4.3.57), Tauranga (5.3.57), Maramarua (6.3.57), Tuakau (7.3.57), and Palmerston North-Pahiatua (25.3.57), indicating its widespread occurrence in North Island areas south of Auckland.

Fam. COCCINELLIDAE (Ladybird Beetles)

The great majority of the species belonging to this family are carnivorous in both the larval and adult stages, living for the most part on soft-bodied insects such as aphids, coccids, and mites. For this reason many are extremely valuable biological control agents. Some species are phytophagous, however, and these include serious pests.

Co. 9. *Scymus* sp.

This species was taken in 7 paddock (7 specimens) and 5 roadside (5 specimens) samples from Victoria Valley (16.1.57), Kerikeri

(18.1.57), Ruakaka (21.1.57), Warkworth (22.1.57), Paekakariki (31.1.57), Gisborne-Tiniroto (12.2.57), Tolaga Bay (12.2.57), Opotiki (14.2.57), Te Kuiti (8.3.57), Mapiu (8.3.57), Taumarunui (8.3.57), and Tarata (2.4.57), indicating its widespread occurrence in the North Island.

Nothing is known of the habits of this species, but it probably has a minor beneficial role in pastures.

Co. 10. *Coccinella 11-punctata* L.

This is a cosmopolitan species well known for its beneficial effects in helping control aphid populations. In the present survey it was taken in 3 paddock (3 specimens) and 4 roadside (5 specimens) samples from Dargaville (22.1.57), Warkworth (22.1.57), Woodhill (23.1.57), Horotiu (23.1.57), Bulls (30.1.57), Maraekakaho (11.2.57), and Wallingford (26.3.57), indicating its widespread occurrence in the North Island.

Any beneficial effects on pasture will be due to reductions in aphid or mite populations. The extent of these benefits is difficult to gauge with any certainty. In the case of parasitic or predaceous species, the numbers encountered are not necessarily related to their value as controlling agents, for balance at low levels is often established. There is also the possibility of control of the aphids, etc., associated with pasture weeds.

Co. 30. *Coccinella tasmanii* White

This endemic species was taken in a paddock sample from Te Pohue on 15.2.57 (1 specimen) and in a roadside sample from Ohakune, 18.3.57 (2 specimens). The habits are not known, but are probably similar to those of the species immediately preceding.

Fam. Lathridiidae

Insects belonging to this family are essentially fungus feeders, although some members apparently feed on mycetozoa. They are not regarded as being of importance in agriculture.

Co. 1. *Melanophthalma gibbosa* Herbst.

This is a cosmopolitan species. In the present survey it was taken in 41 paddock (140 specimens) and 52 roadside (280 specimens) samples, the greatest number being in a roadside sample from Waverley on 24.1.57 which yielded 28 specimens. This species was taken in January (28 samples), February (17), March (44), and early April (4). The distribution encountered is shown in Fig. 1, which indicates its widespread occurrence in the North Island.

Co. 20. *Melanophthalma* sp.

This species was taken in roadside samples from Eketahuna-Pahiatua, 25.3.57 (3 specimens) and Taueru, 25.3.57 (1).

Fig. 1.—Distribution map for the lathridiid *Melanophthalma gibbosa* (Co. 1.)

Co. 27. *Lathridius dualis* Broun

Single specimens of this species were taken in roadside samples from Otaki (31.1.57), and Kohinui (28.3.57), and in a paddock sample from Tutira (11.2.57).

Fam. MYCETOPHAGIDAE

Most species in this family are associated with fungi, and for this reason have not been considered important in agriculture.

Co. 6. *Triphyllus serratus* Broun

A single specimen was taken in a paddock sample from Gisborne-Tiniroto on 12.2.57.

Fam. PYTHIDAE

The habits of this family are poorly known, but species are not considered to be important in agriculture.

Co. 16. *Salpingus simplex* Broun

A single specimen was taken in a paddock sample from Foxton on 4.4.57.

Fam. Anthicidae

Insects belonging to this family are usually found amongst damp vegetable refuse. They are not important in agriculture.

Co. 17. *Anthicus floralis* L.

This is a cosmopolitan species. In the present survey it was taken in paddock samples from Te Kauwhata, 23.1.57 (1 specimen), and from Foxton, 4.4.57 (2).

Fam. Chrysomelidae

The members of this very extensive family are phytophagous or xylophagous species, and include many serious agricultural pests.

Co. 5. *Inopelonia testacea* Broun

This New Zealand species belongs to the subfamily Halticinae or flea beetles, so-named because of their amazing powers of leaping. In the present survey it was taken in 27 paddock (133 specimens) and 16 roadside (18 specimens) samples, the greatest catch (26 specimens) being in a paddock sample from Porangahau on 26.3.57. This species was taken in January (14 samples), February (9), and March (20). The distribution encountered is shown in Fig. 2, which indicates its widespread occurrence in the North Island.

The importance of this species cannot be gauged without close study, but in view of its systematic position and the numbers encountered, it should be regarded with some suspicion.

Co. 25. *Eucolaspis* sp.

This species was taken in roadside samples from Alton 24.1.57 (6 specimens), Waverley, 24.1.57 (7), and Kai Iwi, 24.1.57 (6), and in the paddock sample from the last-named (1). This is possibly *Eucolaspis brunneus* F. better known as the "bronze beetle" and studied in detail by Lysaght (1930). It is not generally regarded as important in pastures, and in the present instance may be associated with weeds.

Fam. Anthribidae

Species belonging to this family are usually associated with rotting wood and fungi, and are not considered to be of importance in agriculture.

Co. 2. *Exilis* sp.

This species was taken in 9 paddock (9 specimens) and 13 roadside (36 specimens) samples, the greatest number being 11 in a roadside sample from Levin on 31.1.57. It was taken in January (11 samples), February (7), and March (4). The distribution met is shown in Fig. 3 which indicates its widespread occurrence in the North Island. Unless it should prove an agent in the transmission of harmful fungus diseases in pastures, it is unlikely to prove of importance.

Fig. 2

Fig. 3

Fig. 2.—Distribution map for the chrysomelid *Inopelonia testacea*. (Co. 5.)

Fig. 3.—Distribution map for the anthribid *Exilis* sp. (Co. 2.)

Fam. APIONIDAE

Insects of this family are often associated with seeds, roots, or stems, and some are injurious to leguminous crops.

Co. 3. *Apion ulicis* Forst. (Gorse Seed Weevil)

This European species is well known in New Zealand. It was introduced in an attempt to help control the spread of gorse (Davies 1928), and is now widely distributed in the country. In the present survey it was taken in 3 paddock (4 specimens) and 2 roadside (2 specimens) samples from Helensville (23.1.57), Te Kauwhata (23.1.57), Piopio (24.1.57), and Kai Iwi (24.1.57). Strangely enough there did not appear to be any gorse in the immediate vicinity of the sampling sites. As far as is known, this species is host specific, and therefore unlikely to be of importance in pastures.

Fam. CURCULIONIDAE

This very extensive family contains many injurious plant feeders, no parts of plants being entirely free from their attacks. In overseas countries a considerable number of species are known to be injurious to pasture plants, and we must expect troublesome introductions from time to time.

Co. 7. *Catoptes obliquisignatus* Bohem.

This New Zealand species was taken in 5 paddock (10 specimens) and 3 roadside (3 specimens) samples from Eltham (24.1.57 . Piopio (24.1.57), Otaki (31.1.57), Paekakariki (31.1.57), Otorohanga (7.3.57), and Ohakune (18.3.57).

In New Zealand, *Catoptes* spp. have been incriminated as damaging turnips and mangels (Marshall 1931) and *Phormium* (Cumber 1954). Soil sampling surveys have given support to the probability that *Catoptes* in pastures is more damaging and of widespread and common occurrence than has been suspected hitherto. Adults are nocturnal and flightless, and daylight sweeping can be expected to yield only very small numbers even where populations are large.

Co. 11. *Hyperodes griseus* Hust. (Argentine Stem Weevil)

A detailed account of the life-history and damage caused to ryegrass in the South Island by this cosmopolitan species is given by Kelsey (1958). It appears that it is a more important pest of this, than it is of wheat in New Zealand. Kelsey states that the adults "are general feeders on all cruciferous crops, most grasses, clovers, lucerne, and also on all cereals."

In the present survey this species was taken at Himatangi 30.1.57 (2 specimens), Levin 31.1.57 (2), Gisborne 13.2.57 (1), Opotiki-Whakatane 14.2.57 (1), Whakatane 14.2.57 (1), and Paeroa 5.3.57 (1), indicating that it is probably of widespread occurrence in the North Island. Numbers encountered are small, but it seems probable that serious outbreaks do occur in some North Island districts.

Co. 12. *Plintheria brouni* Sharp

A single specimen was taken in a roadside sample from Victoria Valley (Kaitaia) on 16.1.57. It is unlikely to prove of importance in pastures.

Co. 28. *Pantomorus godmanni* Crotch (Fuller's Rose Weevil)

A single specimen was taken in a roadside sample from Tolaga Bay on 12.2.57.

Gourlay (1940) discusses the distribution, economic status, and habits, of this cosmopolitan species and suggests control measures. It is a flightless and nocturnally active species, and one would therefore not expect to obtain numbers in a daylight sweep-survey. This species will be discussed again when the information from soil sampling surveys is presented.

Co. 29. *Acalles* sp.

A single specimen was taken in a roadside sample from Te Pohue on 15.2.57. It is not important in pastures.

There are, in addition to the species mentioned above, four others whose identity is as yet undetermined. They occurred in low numbers

at single localities, and it is unlikely that they should prove of any importance.

DISCUSSION

Pasture sweeping during daylight hours is likely to give a rather poor picture of the importance of this order, which contains perhaps the most important pests of our pastures.

Many species are nocturnal in their habits, and in addition, some restrict their flying activities to selected night hours. Quite often, too, it is the larval stages which cause the greater part of the damage. Soil and turf examinations are therefore likely to be more revealing. It is interesting to note that the relatively common grass grub *Costelytra zealandica* (White) did not appear in the sweep-sampling.

Several species which may be of more importance than has hitherto been recognised, or which may prove to be of greater importance in the future, may be pointed out.

The imported elaterid *Lacon variabilis* may prove to be one of the more common and widespread species, although it has not been detected in large numbers.

The native halticid *Inopelonia testacea* has turned up in moderately large numbers, and must be regarded with some suspicion until its habits are better known.

The presence of the chrysomelid *Eucolaspis* sp. in Taranaki areas is of interest although the numbers present are low.

Mention has been made of the imported gorse seed weevil *Apion ulicis*, in areas where gorse apparently was not present. It is to be hoped that this is a feature of its powers of dispersion rather than an indication of any change in habits.

Amongst the curculionids there are several damaging species. The genus *Catoptes* must be regarded as being of more importance in pastures than has been supposed in the past. Soil examinations have provided additional proof of this. *Hyperodes griseus*, the Argentine stem weevil, is shown to occur at widely scattered localities in the North Island. Its importance as a pest of ryegrass is becoming well known. *Pantomorus godmanni*, Fuller's rose weevil, may yet prove to be a serious pest of pastures. Some serious larval attacks of what is apparently this species, have recently been discovered in North Auckland areas.

There are, however, some species which must be regarded as beneficial to our pastures. Notable amongst these are the coccinellids which doubtless play an important part in controlling the levels of aphid populations.

One rather interesting but speculative aspect is the relatively large number of species whose habits are generally supposed to be associated with fungi. These, together with the many species of flies, may play some part in the dissemination of spores of the fungus species which are troublesome in our pastures.

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SERIOUS OUTBREAK OF THE APHID *Rhopalosiphum padi* (L.) IN NORTH ISLAND WHEAT, OAT, AND BARLEY CROPS DURING 1958

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Summary

An outbreak of the aphid *Rhopalosiphum padi* (L.) in wheat, oat, and barley crops grown in the Feilding, Halcombe, and Bulls areas attained serious levels during the early summer of 1958. The abnormally dry and warm seasonal conditions are regarded as being primarily responsible.

A hurried examination of the problem has provided information which, despite its limitations, is placed on record in view of the desirability of increasing wheat production in New Zealand.

Aerial applications of a systemic insecticide (Metasystox) were made in some areas. An endeavour was made to assess the effects of these on aphids and other insects in treated crops. Owing to the fact that the infestations were declining at the time of spraying the results are rather inconclusive.

Introduction

Early in November 1958, a request was received from Department of Agriculture Field Officers to inspect damage to wheat crops in the Halcombe district with a view to ascertaining whether or not insects were involved. Severe infestations with the aphid *Rhopalosiphum padi* (L.) were found to be affecting crops of wheat, oats, and barley.

Outbreaks of the severity encountered have not previously been recorded in New Zealand, and the present experience makes it highly desirable that all information relative to the outbreak conditions be recorded.

Cottier (1953) states that "This is the common aphid infesting Gramineae in New Zealand. In the field it may be very injurious. It has been observed severely infesting young wheat about a foot tall. From centres of infestation it spreads in ever-widening circles, plants turning yellow and quickly becoming stunted. In the Southland district it has caused similar injury to young oats. Although widely distributed, the species is, however, seldom a severe pest in the field. It is commonly found on maize, but does not appear to cause noticeable injury. The species is very troublesome on Gramineae grown under glass."

Mr J. M. Hoy (pers. comm.) recalls that minor infestations in barley in the Kimbolton and Glen Oroua areas occurred in 1955.

Discussions with growers in the outbreak areas reveal conflicting evidence of damage in past seasons. One who had grown wheat for

the past 30 years had not experienced a previous outbreak, whereas another maintained that there was usually damage of one degree or another.

Mr J. L. Graham of the Department of Agriculture (pers. comm.) has indicated that currently in some areas young ryegrass heavily infested with the aphid was dying out. Considerable populations were also found in longer closed pastures in the Marton district during the summer of 1957 (Cumber 1959) which was also unusually dry.

Results

Survey of Affected Areas

Surveys in the Feilding, Halcombe, Marton, and Bulls districts were carried out 11-15 November. The wheat was predominantly of the "Gabo" and "Tainui" varieties.

The most severe damage encountered was found on the northerly faces in rolling country (Fig. 1). These faces produced the first symptoms easily discernible from a distance, but damage on flats and westerly aspects also became evident at later dates.

Fig. 1.—Area 1 showing in the foreground a stunted pocket in a wheat crop and in the background the lighter patchy effect which attends a severe aphid outbreak.

The first evidence of damage to wheat was noticed by farmers during the last week of October when a faint yellowing and a general unthriftiness was visible in crops about one foot high. Within a week these symptoms had extended to a severe yellowing and stunting over

considerable areas, the continuing dry weather causing a rapid deterioration. On one farm alone it was evident that at least 5 acres was so severely affected that yields would be practically nil, and damage over considerably larger areas would cause much reduced yields.

On many farms infestations of varying severity were encountered and damage, sometimes severe, was also evident in oat and barley crops which are later than wheat.

In some stands, very severe infestations were present in lush growth at least two feet tall, the stems being almost completely blackened. Such infested portions, often of about 10 square yards or so in extent, showed a slight reduction in height indicating a rapid build up of the pest at a comparatively late stage in the growth of the crop. In other areas where earlier crops were about to head up, the stunting caused by the attack was much more evident, and a relatively sharp boundary between affected and adjacent unaffected portions suggested that the attack was being contained in some measure. Possible explanations for this were the build up of the aphid parasite-predator complex, and the passing of the more succulent, vulnerable stage of growth. In some spots the ground seemed alive with aphids driven no doubt by overcrowding and exposure to the heat of the sun, to migrate to the more shady adjacent less affected portions of the stand.

In some badly affected portions of older wheat stands the aphid population peak appeared to have passed. In younger wheat, oat, and barley crops about 6–9 inches in height, a yellowing and stunting was in many cases very evident without an obvious aphid build-up. A close examination of plants in such areas, however, showed a considerable infestation at or slightly below ground level on the succulent leaf sheaths.

It was evident in the areas studied that the aphid build-up had commenced at a relatively early stage in growth and that the most damaging period is probably when crops are between 6 inches and 1 foot in height, at which time rapid tillering should be taking place. Winged aphids from adjacent grassed areas obviously reach all portions of the crop shortly after it is established, and in the course of some 4–6 weeks build up to damaging numbers at ground level. The disappearance of basal succulence and overcrowding result in a movement up the plants. Severe infestations give rise to short, sparse plants which quickly run to head.

An understanding of the course and symptoms associated with these aphid attacks makes possible the recognition, in mildly affected crops, of setbacks received during their establishment. In the past such unthriftiness has often been attributed to other causes.

The Predator-Parasite Complex

Wherever the infestation was advanced and severe, there was a considerable build up of predators and parasites, and there can be little

doubt that the measure of control which they exercise is very considerable. However, they appear unable to cope with the aphid build-up during the stages of crop establishment.

The lady-bird beetle *Coccinella 11-punctata* L. was present in all stages and in very considerable numbers. A lump of earth the size of one's fist might harbour as many as 20 pupae or pupal skins and several egg masses on its lower surface. This species is probably the main controlling agent. A second undetermined coccinellid species was present in small numbers. In the Syrphidae, *Syrphus novae-zealandiae* Macq. was much in evidence both as adults and larvae, and a few adults of *Melanostoma fasciatum* Macq. were seen. The former is doubtless a very beneficial species in the present complex. Larvae and adults of the hemerobiid *Micromus tasmaniae* Walk. were present, as were several small hymenopterous species. There also appeared to be considerable mortality due to fungus attacking the aphids.

Weather Conditions Associated with the Outbreak

The aphid species concerned has been in the country for many years, and doubtless most crops of wheat, barley, and oats regularly show low-level infestations throughout. It has been assumed that the epidemic level reached in the present instance is due to the unusually dry and warm conditions prevailing during August, September, and October, which has enabled the faster-breeding aphid to outstrip the usual regulatory parasite and predator complex.

Table 1, based on readings made at the Grasslands Division, Department of Scientific and Industrial Research, Palmerston North, summarises by weeks the average maximum and minimum temperatures (screened) and the total rainfall, for the period 1 August to 6 November 1958.

TABLE 1. Details of Weather Conditions

Period	Average Temperature °F		Total Rainfall (in.)
	Minimum	Maximum	
Aug. 1– 7	35.7	52.9	5.38
8–14	42.4	58.3	1.20
15–21	38.3	57.4	0.68
22–28	42.7	55.8	1.97
29– 4 Sep.	39.4	55.9	0.57
Sep. 5–11	42.9	60.1	Nil
12–18	42.1	58.5	0.19
19–25	44.1	61.1	0.05
26– 2 Oct.	40.7	65.2	Nil
Oct. 3– 9	50.0	67.9	0.29
10–16	44.9	57.5	0.39
17–23	53.5	67.9	1.05
24–30	51.1	68.3	0.59
31– 6 Nov.	48.5	67.8	0.31

Fig. 2.—Spray boom equipment attached to the Piper Cub aircraft.

Fig. 3.—Pilot and mixer-filler assistant wearing protective clothing.

Fig. 4.—Equipment used in mixing the spray and filling the aircraft. The pilot (right) is attending the filler motor.

Fig. 5.—The loaded plane prepares to take off and spray the wheat crop seen in the background.

Fig. 6.—The spray is applied from a height of 8-16 ft.

Use of Insecticides

The decision to use insecticides was made following the discovery of heavy active infestations in dense wheat stands which were about to run to head and in the younger barley and oat crops which were showing severe yellowing and stunting due to damage at the base of the plants.

A systemic insecticide appeared to be the most satisfactory for several reasons. It seemed the only way to reach all aphids, that is, the infestations present in the moderately dense older stands of wheat, and the basal ground level infestations in the younger crops more particularly of oats and barley. Systemic insecticides are also regarded as being the least severe on the predator-parasite complex which in the present instance was obviously exercising a considerable beneficial effect. Application by aircraft seemed to be the most practicable method. Metasystox, which was selected in the present instance, has already been used with considerable success against the cabbage aphid *Brevicoryne brassicae* (L.) in the South Island (Lowe 1958). Aerial spray at the rate of $\frac{3}{4}$ of a pint to ten gallons of water per acre was applied to a severely affected area of wheat (70 acres) at Halcombe (Area 1, Table 2) on 16–17 November. This crop (Fig. 1) which was shortly to head up, was severely damaged, and although serious active infestation centres were present, the pest appeared to be on the decline. A second crop of wheat (40 acres) at Awahuri (Area 3, Table 2) was sprayed on 19 November. Prior to spraying,

stunting and some yellowing was evident and moderate numbers of aphids were present at ground level. A barley crop in the Halcombe area, which was severely yellowed and showed signs of stunting, was sprayed on 17 November. Untreated crops of wheat and barley at similar stages of infestation were available in the district for rough comparison purposes.

On account of the density of some affected crops, recommendations were made for aerial spraying to be carried out at dilutions greater than those finally adopted. The applications were carried out by Aerial Farm Holdings Limited with a boom-equipped Piper Cub cabin aircraft (Fig. 2). Pressures of 35 pounds per square inch and $\frac{1}{8}$ inch nozzles were used. An officer of the Department of Health was present to supervise the use of protective clothing and check factors such as drift and proximity to highways. The protective equipment and mixing operation are shown in Figs. 3, 4, and 5. The spray was applied (Fig. 6) in the early mornings at heights ranging from 8 to 16 feet. In the spraying operation illustrated, refilling of the aircraft took place at about 7-minute intervals, and the cost, including that of the spray materials, was in the vicinity of 50 shillings per acre. Despite warnings, farmers chose not to remove stock from adjacent areas. However, drift was kept to a minimum and the stock usually moved to the distal portions of adjacent paddocks during the actual operations.

Insects Encountered in Sprayed and Non-sprayed Areas

Because of the limited time available and difficulties associated with numerical checkings of changing aphid populations, it was not possible to assess the results of spraying in the present instances except by means of limited sweep-net comparisons and general observation of comparable treated and non-treated areas. Sweepings were made with a net of the detachable sock design (Cumber 1958). Two samples were taken per crop examined, each sample comprising 20 sweeps of the net. Table 2 indicates the total insects taken in each order, and Table 3 gives information on the identity of the species encountered.

It seems evident that, as was expected, the aphid population was already on the wane in the older, more severely affected areas. The same probably applied to the collembolan populations. It is possible, too, that the thrips population in Area 1 may have received a set-back due to spraying, but this did not prevent a build-up 2–3 weeks later. There is insufficient experimental evidence to suggest other results.

In the case of the areas of barley mentioned above, the one sprayed on 17 November was free from aphis when examined on 3 December, whereas the untreated area still showed moderate although reduced numbers.

It is of interest to record that aerial spraying of wheat had been carried out independently in an area north-west of Bulls during the first week of November. The crop had shown typical patchy yellowing on the northern faces and agents had recommended aerial applications of

TABLE 2. DETAILS OF INSECTS TAKEN WITH SWEEP NET FROM AFFECTED WHEAT AREAS

Order	Area 1 (Sprayed 16-17/11/58)						Area 2 (Untreated)				Area 3* (Sprayed 19/11/58)			
	11/11/58		25/11/58		3/12/58		25/11/58		3/12/58		25/11/58		3/12/58	
	Sample 1	2	1	2	1	2	1	2	1	2	1	2	1	2
Coleoptera	24	16	1	2	—	3	—	—	1	—	—	—	—	—
Collembola	600	60	—	—	—	—	3	2	—	4	8	—	—	—
Diptera	16	6	13	12	7	6	13	12	19	6	54	24	18	84
Hemiptera	1200	160	1	—	—	—	3	1	—	—	16	8	3	2
Hymenoptera	19	13	4	1	8	2	3	3	1	6	6	—	2	1
Lepidoptera	—	Larvae 2 Eggs 300	—	—	—	Larvae 4	2	4	1	Larvae 2	2	—	4	—
Neuroptera	2	2	—	—	4	—	1	—	—	—	—	1	1	—
Thysanoptera	10	4	1	3	66	48	86	92	38	68	30	16	112	25

* Samples 1 marginal, 2 central

TABLE 3. INSECT SPECIES ENCOUNTERED

Coleoptera	*Atheta* sp. Staphylinidae
	**Coccinella 11-punctata* L. Coccinellidae
	Undetermined sp. Coccinellidae
	Melanophthalma gibbosa Herbst. Lathridiidae
	Hyperodes griseus Hust. Curculionidae (Argentine Stem-weevil).
Collembola	Undetermined symphypleonid
Diptera	Undetermined sp. Tipulidae
	Undetermined sp. Psychodidae
	Undetermined spp. (3) Chironomidae
	Undetermined sp. Dolichopodidae
	Melanostoma fasciatum Macq. Syrphidae
	Syrphus novae-zealandiae Macq. Syrphidae
	**Cerodontha denticornis* (Panz.) Agromyzidae (Wheat sheath-miner)
	Phytomyza atricornis Meig. Agromyzidae
	Scaptomyza fuscitarsis Harr. Drosophilidae
	Psilopa metallica (Hutt.) Ephydridae
	Hydrellia ? enderbii (Hutt.) Ephydridae
	Undetermined sp. Tachinidae
Hemiptera	*Erythroneura zealandica* Myers Jassidae
	**Rhopalosiphum padi* (L.) Aphididae
	Calocoris norvegicus (Gmelin) Miridae
Hymenoptera	*Bassus lactatorius* F. Ichneumonidae
	Chorebus sp. Braconidae
	Trioxys sp. Braconidae
	Aprostocetus sp. Eulophidae
	Trichogramma sp. Trichogrammatidae
	**Lygocerus* sp. Ceraphronidae
Lepidoptera	*Coleophora* sp. Coleophoridae
	Crambus flexuosellus Dbld. Crambidae
	*Undetermined sp. Noctuidae (mainly eggs, larvae)
Neuroptera	*Micromus tasmaniae* Walk. Hemerobiidae
**Thysanoptera	*Aeolothrips fasciatus* (L.) Aeolothripidae
	Anaphothrips spp. (2) Thripidae
	Aptinothrips sp. Thripidae
	Chirothrips sp. Thripidae
	Haplothrips niger Osb. Phlaeothripidae

* Major representative in the order.

** The species other than *Aeolothrips* and *Aptinothrips* were all present in moderate numbers.

DDT. This was applied at the rate of 3 pints to 10 gallons of water per acre. An examination of the area on 12 November showed it to be free from the aphid, but in view of the history of untreated comparable crops the results are not necessarily due to the spraying with DDT.

Effects of Metasystox on Personnel

During earlier operations the pilot and filler-mixer assistant experienced a certain flavour in the mouth somewhat similar to that caused by excessive smoking. Later a different type of respirator was adopted and the flavour eliminated. Lowe (1958) also reports a taste in the mouth during previous experiments but describes this as "salty". On the morning of the 16th shortly after operations commenced, a wind sprang up suddenly and caused some drift before the operation was stopped. The smell of the insecticide was reported by a farmer 2 miles distant. On the 17th a similar short drift period across a cowshed some 200 yards away caused one occupant to be affected with drowsiness and severe headache for the remainder of the day. Two children similarly exposed were apparently unaffected. A farmer approximately half a mile distant complained of the smell and a transitory headache. The authors witnessed the spraying operations on 19 November which commenced at 6 a.m. in still frosty conditions. The materials were handled safely and precisely.

DISCUSSION

The limitations set by the nature of the present work, and the importance of summarising all available information have already been stressed. It is obvious that there is a considerable need for further detailed studies of the insects associated with wheat crops in New Zealand. Although varying rainfall and attendant soil moistures from season to season must be regarded as the basic factor in the range of yields experienced, it seems highly probable that fluctuations in insect populations which attend the varying weather conditions are also responsible in no small measure. Evidence for this becomes apparent only under extremes of weather conditions such as have preceded the present outbreak.

The amount of insect damage which may be obviated in the average season can be calculated only by systematic experimentation. Only then will it be possible to assess the desirability of treatments to increase yields. Treatments may be most effectively applied only when the details of the life history of the offending species, and their most vulnerable stages, are known. A recognition of the great value of the biological control complex and the need to safeguard this as far as is possible is also very important.

It seems probable that in average seasons many areas of wheat, oats, and barley experience a moderate build-up of the aphid pest and that it has some effect upon yields. The vulnerable stage appears to be when crops are about 6 weeks old. In these young crops the protection afforded by uneven ground, and the succulence at the base of the plants, enables populations of the aphid to build up at ground

level. Severe attacks at this stage result in stunting, yellowing, and a general unthriftiness and sparseness. This is a very critical stage in the growth of the crop. Crops which pass the younger vulnerable stage without apparent setbacks may still suffer in the tall, lush, pre-heading stages, for the rising aphid population may extend its attack to the upper portions of the plant and at times completely blacken the stems and leaves. This is soon followed by wilting and penetration by the sun's rays. The population then drops to the ground and disperses to surrounding portions of the stand.

Other pests which one might hope to help control by the use of a systemic insecticide at the appropriate time are the Argentine stem-weevel, the wheat sheath-miner, thrips, and armyworms. One untreated area of wheat in the districts concerned here showed a 5–10% infestation of stems by the first-mentioned pest. This will undoubtedly decrease the yields to a comparable degree.

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VERTICILLIUM WILT OF TOBACCO

I. A NEW DISEASE OF TOBACCO CAUSED BY *Verticillium dahliae* Kleb.

By R. Thomson and A. G. McLeod, Tobacco Research Station, Department of Scientific and Industrial Research, Motueka

(*Received for publication, 13 March 1959*)

Summary

Verticillium wilt of tobacco is described and the extent of the affected areas defined.

Soil treatment with either chloropicrin or methyl bromide controlled the disease but their use is uneconomic except for eliminating small centres of infection.

No cultural or rotational treatment tried reduced the amount of infection sufficiently to suggest a method of control.

Introduction

In February 1944, an unusual condition was observed in the crop of a Motueka grower. Approximately half an acre was seriously affected and other plants showing the disorder were scattered throughout the crop. Appearance of the tobacco suggested a pathogenic condition but symptoms were quite different from those of any disease observed elsewhere or described in literature. Dr K. M. Curtis, Cawthron Institute, Nelson, identified the causal organism as a strain of *Verticillium dahliae* Kleb and demonstrated its pathogenicity. Since then the disease has been recorded on a number of other properties and the original centres of infection have enlarged. On some areas the disease has become so severe that economic production of tobacco is no longer possible.

This appears to be the first record of verticillium wilt as a major disease of tobacco. Wolf (1935) reports isolating *V. albo-atrum* from a tobacco plant in Tennessee, and Hopkins (1956) records finding a species of *Verticillium* on the roots of tobacco, but in neither of these instances was there any suggestion of more than an occasional plant involved.

Description

The outstanding characteristic of the disease is the orange colour of the wilted leaves. External evidence of wilt is not apparent until the plant commences flowering. The first symptoms are the wilting of one or more leaves, particularly in hot weather. This is followed by the interveinal area turning a bright orange colour. (Fig. 1.) As the disease progresses, the tissue dies and turns brown leaving an orange border between the living and dead tissue. At first, symptoms are restricted to one or two leaves, and while these are generally low down on the plant, they may occur at any height. Eventually there is a complete breakdown of all leaves (Fig. 2).

Fig. 1.—Early stage. Interveinal areas bright orange.

In cross section, the vascular tissue of the leaf midrib shows a light-brown discolouration. Roots on the other hand show no symptoms. Wilting is most severe and the typical orange colour develops most rapidly when heavy rain or irrigation follows a dry spell. As symptoms do not appear until the crop is in flower, it is usually possible to harvest one or two pickings. Once the disease makes it appearance it progresses faster than the leaf ripens and the remainder of the crop is lost.

EXTENT OF INFECTION

Since the 1943-44 season a number of other infected areas have been found, and the map (Fig. 3) shows the present known distribution on tobacco-growing areas. Some of these infections appear to be of long standing while others are of more recent origin. The total infected area is approximately 70 acres, of which some 30 acres are so badly infected that tobacco production is no longer economic. Of the remaining 40 acres some 15 acres are severely infected.

It has not been possible to establish the source of the original verticillium wilt infection but three separate centres appear to exist. In one locality the disease first appeared on an area which had been the site of a flower and vegetable garden. In a second instance the land had previously been used for commercial gardening with tomatoes and potatoes predominating. It is probable that the disease originated in one of these crops and a strain adapted itself to the subsequent tobacco crop. No such previous cropping history is apparent for the area on which the disease was first discovered.

Fig. 2.—Late stage. Dead interveinal areas brown. All leaves affected.

The spread of the disease is easier to follow. It has been established that the disease is soil borne and attacks the plants through the roots (Bewley 1922). The chief areas of infection are adjacent to the lower reaches of the Motueka river and a study of the map (Fig. 3) shows that these all border on a flood-water course. Distribution in Riwaka can also be traced along the line of flow of surface water. The chief source of new centres of infection thus appears to be the movement of infected soil and plant debris by water. Some of the instances of sporadic infection, which are widely separated from the river-bed area, occur on farms where implements have previously been used or stock grazed on heavily infected areas and then transferred to clean ground. This appears to be a lesser but still important means of spread. The possibility of dissemination by air-borne spores cannot be overlooked, but there is no field evidence of spread in this manner.

Fig. 3.—Extent and distribution of affected areas, April 1957.

Although *Verticillium dahliae* may increase very rapidly in other crops such as tomatoes, with tobacco the increase in size of an infected area has been at a slow steady rate. This slow progressive spread is in accordance with the conclusions of Isaac (1953) that *V. dahliae* is incapable of spreading as a saprophyte through the soil and that spread of the disease takes place by contact between dying infected roots and healthy roots with a rapidity proportional to that of the death of the roots of the host plant.

EXPERIMENTAL WORK

Trials were commenced in 1944 to determine the effect of various soil fungicides, cover crops, and cultural practices on the incidence of wilt.

In 1944 half of the original diseased area was sown to pasture and the following year the remaining portion was grassed down. In 1949 the whole area was ploughed up and planted to tobacco. Although the incidence of wilt was not as great as in 1943-44 it was still too

severe for an economical tobacco crop. Thus a spell in grass for periods of 4 and 5 years did not result in a satisfactory measure of control.

SOIL FUNGICIDES

In 1947-48 an area on which wilt had been present for several years and which in 1946-47 had shown 80–90% infection was made available for field trials. Plots 18 ft × 9 ft were enclosed by 8 in. boards let 6 in. into the ground, and on 14 November were treated with chloropicrin applied with a hand injector at 4 ml per square foot. The area was then watered, covered with wet sacks for three days, and three weeks later planted with tobacco. No sign of wilt appeared in the treated area although the disease was severe in the untreated controls. The following three seasons the trial was repeated on other sections of the heavily infected area. In 1948-49 and 1949-50 complete control was obtained with chloropicrin but in 1950-51 two infected plants appeared in the treated plots.

In 1948-49 and in 1950-51 DD (dichloropropene dichloropropane) was included in the trials and was applied at 3 ml and 4 ml per square foot respectively, the procedure adopted being the same as that for chloropicrin. In the first season there was some reduction in the amount of wilt present, but in the second trial DD had no apparent effect on the incidence of the disease.

Because this particular area of land was no longer available, trials were discontinued until 1956-57 when the use of another area was secured. This area had grown tobacco continuously for a number of years and was heavily infected with verticillium wilt. Plots 25 ft × 15 ft were treated with chloropicrin, applied with a hand injector at 4 ml per square foot on 26 October. No water seal was used, the points of injection being covered over and pressed down firmly with the foot. Another plot was treated with methyl bromide, released under a plastic cover, at the rate of 1 lb per 100 sq. ft. Tobacco was planted late in November. Wilt counts made in February were as follows:

Untreated	82.6%
Methyl bromide	6.2%
Chloropicrin	1.1%

On another farm where a similar trial was carried out, the distribution of wilt was too scattered and irregular for counts. However, both chloropicrin and methyl bromide reduced the amount of wilt to practically nil.

Chloropicrin, having proved satisfactory for the control of wilt, was tried on a semi-commercial scale in 1957-58, using a tractor-mounted applicator. This proved irregular in operation and applied only 2.2 ml per square foot. Results are as follows:

Complete coverage with chloropicrin	39.6%
Row application only	81.3%
Untreated	90.4%

Some degree of control was secured with the overall treatment but owing to insufficient quantity and irregular application this was not as complete as in previous trials. Row application was ineffective.

Wilt counts taken in the plots treated twelve months previously were:

Chloropicrin	50 %
Methyl bromide	34.3%
Control	75 %

There has been some residual benefit. Subsequent cultivation could well have been responsible for re-contaminating the clean plots.

Cover Crops

In 1949-50 a trial was commenced to determine the effect, if any, of various cover crops and cultural practices on the carry over of wilt.

The trial was located on a portion of the severely affected area and the plots were prepared as described before by letting boards 6 in. into the ground. There were two replications of each treatment.

Various cover crops were sown on 5 April and all made excellent growth except the lupins, which were rather sparse. All were dug under on 30 September, tools being washed with formalin between each plot. Twenty-four tobacco plants were set out in each section on 18 November, and counts of wilt infection were made at the end of the season. The trial was repeated in 1950-51, the same cover crops being planted on the same sections. These were dug in and tobacco again planted. Wilt counts for the two seasons are given in the following table:

	1949-50 % wilt	1950-51 % wilt	Av. of 2 seasons
Italian ryegrass	31	30	30.5
Italian ryegrass and red clover (two year growth)	—	40	40
Oats and vetches	42	44	43
Ryecorn	25	33	29
Lupins	52	50	51
Fallow	44	35	39.5
Stalks removed	73	50	61.5

While no cover crop effectively reduced the incidence of wilt the lowest percentages of infection followed the two graminaceous crops, ryegrass and ryecorn. Legumes alone, or mixtures containing legumes, had a higher infection, while the most wilt occurred on the plots from which the stalks had been removed.

To determine whether there was any possibility of wilt infection being spread by handling, trials were conducted in which the ordinary operations of picking, topping, and lateralling were carried out, first in wilt-infected plots and then immediately afterwards in healthy plots

by the same operators. In two seasons there was no evidence that there had been any spread of infection by handling.

DISCUSSION

Verticillium wilt has become established as a serious disease of tobacco. Potentially it is the most serious disease of the crop in New Zealand. The 30 acres already out of production represents just under 1% of the total area grown. At present there is no prospect of their coming back into production and the wilt is increasing on other farms. Tobacco farms are small in area and highly capitalised with buildings. These two factors operate against growing on other areas. The trials have established two points, that verticillium wilt can be controlled by soil fumigation with chloropicrin and methyl bromide, and that no simple rotation or cultural practice has as yet been effective in reducing the amount of infection, although the incidence of wilt following grass or cereal was less than that following legumes. With either chloropicrin or methyl bromide, costs for material alone would be over £160 per acre, in addition to which would be the cost of application. If wilt could be eliminated for a period of years these chemicals might be useful in keeping valuable land in production, but treatment every one or two years would be uneconomical. As spot treatments to eliminate small centres of infection, both chloropicrin and methyl bromide can be recommended as being useful in preventing the further spread of the disease.

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VERTICILLIUM WILT OF TOBACCO

II. FIELD AND GLASSHOUSE TRIALS TO DETERMINE RESISTANCE OF VARIETIES AND SPECIES TO *Verticillium dahliae* Kleb.

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(*Received for publication, 13 March 1959*)

Summary

Results of growing 66 varieties, 33 species, and the progeny of 20 *N. tabacum* crosses are presented.

Expression and intensity of infection varied according to the season. Symptoms were expressed only after the plant had reached maturity. No varieties or species showed immunity, but two varieties appeared to have a degree of field resistance.

Introduction

In 1947, resistance to verticillium wilt was included as a project in the breeding programme at the Tobacco Research Station. As the disease is not a major problem in the tobacco-growing areas of other countries, there is no record of the screening of tobacco varieties or *Nicotiana* species for resistance to *Verticillium dahliae*.

Field Methods

Approximately half an acre of uniformly heavily infected Riwaka coarse sandy loam was used in these trials. To maintain the inoculum potential at a high level, infected material was disced under each year. A winter cover crop of ryecorn was sown at the end of each growing season, and cultivation, fertiliser, and cultural methods followed those of normal tobacco-growing practice (Thomson 1944).

From 1947-48 to 1953-54 all the available varieties and *Nicotiana* species were grown to determine their resistance to verticillium wilt. Rows were 3 ft 6 in. apart, 30 plants long, and plants were spaced at 12 in. within the row. Where a variety showed a high percentage of infection it was grown for one year only. Where the amount of infection was low the test was repeated for 2 or 3 seasons.

Two varieties, Ky 34 and TI 448 A, which appeared to have some degree of field resistance, were crossed with the commercial variety Harrison's Special, and the progeny grown on infected land and studied in subsequent years.

In 1951, from an adjacent area of some three acres of Harrison's Special showing almost 100% infection, eleven plants exhibiting no symptoms were selected and the progeny grown during the following seasons.

As a check on visual symptoms (Thomson and McLeod 1959), laboratory isolations were made periodically by the mycologists of the Cawthron Institute.

Field Results

Although the primary objective was discovery of sources of resistance, additional information on the disease was obtained.

The amount of wilt and the intensity of symptoms varied in different seasons. In 1950, 1951, and 1953, infection in Harrison's Special, both in the trial area and the adjacent crop, was over 90%. In 1948, 1952, and 1954, only 50–60% infection occurred. When infection was high (above 90%), symptoms were expressed intensely. Wilting of green leaves was marked, the interveinal areas quickly developed a deep orange colour and death of the plant occurred within four weeks. When infection was low (50–60%), wilting of green leaves was less severe, and death of the plant did not occur until the end of the season. Heavy rain or irrigation, following a dry spell, such as occurred in February 1950 and January 1951 and 1953, appears conducive to a severe manifestation of the disease, while with a more even distribution of rainfall, as in 1948, 1952, and 1954, symptoms were much less pronounced.

The appearance of wilt was closely linked to seasonal conditions. Thus with an early variety the first symptoms of wilt could appear early in January or may be delayed until the end of February. In late seasons, late-maturing varieties did not exhibit symptoms of the disease.

The varieties and species tested are listed in Table 1. Of the late varieties, Corcoote, Franco Corto, Samsoun, and Trapezund were more severely affected than Harrison's Special, while Amarello, BLMR, LOMR, LCMR, TI 448 A, and TL 106 were less severely affected. Mid-season lines listed as less susceptible than Harrison's Special were DB 101, Vesta 33, Ky 34, and Oxford 1, 3, and 26. Of the less susceptible varieties, Ky 34, TI 448 A, and Amarello initially appeared to be immune. Later these varieties all showed some wilt symptoms, Ky 34 in the fourth year, TI 448 A in the fifth year, and Amarello in the sixth year of testing.

Other *Nicotiana* species in general were not so badly affected, nor were the symptoms expressed identical with those in *N. tabacum*. There is a division between species which show some yellowing and wilting and others in which only browning of the leaves occurs. *V. dahliae* has been isolated from stems and midribs of all in this latter group. This browning of the interveinal area of the leaf is not preceded by wilting nor does the plant appear to be killed, as young lateral shoots develop. With these bushy annuals it is difficult to decide whether the older section has been killed by the pathogen, as normally the centre stems mature and die while the outer and younger stems show vigorous vegetative growth. None of the species showed a degree of resistance which would make them useful parental material in the breeding programme.

TABLE 1. VARIETIES AND SPECIES GROWN IN INFECTED SOIL

Symptoms More Severe than in Harrison's Special

Basma Seres	M	Haronova	M	Suri Almyros	M
Basma Xanti	M	Marvos d'Thessaille	M	Siridilli	M
Chino Hybrid	L	Murodatus d'Agrinon	L	Sumatra Mietlinskaja	M
Corcoote	L	Murodatus Smyrna	M	Trapezund	M
Caba Culack	M	Perustiza	M	Tsambelli d'Agrinon	M
Franco Corto	L	Salom	L	Tiki Kulak	M
Guacharo	L	Samsoun	L	Yalomita	E
				No. 100	L

Symptoms Equally Severe as in Harison's Special

Ambalema	L	Ky 33	M	Vesta 52	E
Argos	L	Ky 41A	M	Vesta 53	M
Bottom Special	E	Pennsylvania Seed Leaf	L	Vesta 55	M
Connecticut Havana	M	R.G.	L	Vesta 62	M
Cavalla	L	Special 400	M	Vesta 64	L
Delcrest	M	Special 402	M	Vamorr 48	M
DB 102	M	Vesta 11	M	Vamorr 50	M
Florida 301	M	Vesta 26	M	Virginia Gold	M
Harrison's Special	M	Vesta 30	M	Xanthi	E
Harmony	M	Vesta 46	M	Zahradni Ruzovy	
Hicks	E	Vesta 47	M		

Symptoms Less Severe than in Harrison's Special

Amarello	L	LCMR	L	Oxford 26	L
BLMR	L	LOMR	L	TI 448 A	L
DB 101	M	Oxford 1	M	TL 106	L
Ky 34	M	Oxford 3	M	Vesta 33	M

Species that Have Shown Yellowing and Wilting

N. angustifolia	*N. glutinosa*	*N. langsdorffii*
N. alata	*N. glauca*	*N. macrophylla*
N. attenuata	*N. gigantea*	*N. plumbaginifolia*
N. bigelovii	*N. ipomopsiflora*	*N. quadrivalvis*
N. campanulata	*N. laterima*	*N. rustica*
N. calyciflora	*N. laterna*	*N. sylvestris*
N. debneyii	*N. longiflora*	*N. tomentosa*
		N. viscosa

Species that Have Shown Browning of Leaves

N. auriculata	*N. petiolaris*	*N. solanifolia*
N. acuminata	*N. petiolata*	*N. suaveolens*
N. fruticosa	*N. paniculata*	*N. texana*
		N. rotundifolia

L = Late; M = Mid season; E = Early.

Results with the progeny of the 6 crosses between Harrison's Special and TI 448 A, the 4 crosses between Harrison's Special and Ky 34 made in 1949, and the 10 crosses of Harrison's Special and Ky 34 made in 1950, proved disappointing.

In 1950, some F1 lines showed wilt symptoms while others appeared to be healthy. In 1951, the F2 material of TI 448 A origin segregated more widely for type than did the lines of Ky 34 origin, but both contained some plants with desirable agronomic features. Segregation for mosaic resistance (*N. glutinosa* type) followed the expected pattern with Ky 34 crosses. Early in the season all the material gave the appearance of segregating for resistance to *Verticillium*. Counts taken in all lines suggested that resistance was governed by a pair of dominant factors. However, later in the season, most of the material that had been selected as resistant developed wilt symptoms, although several plants remained free at the end of the season. These were grown in the F3 generation in 1952. The majority became infected and the few plants that showed no wilt were selected and the F4 generation grown in 1953. No resistance to the disease was apparent in this material. Similar results occurred with the F2 and F3 generations grown in 1952 and 1953 of the Harrison's Special × Ky 34 crosses made in 1950.

The F1 progeny of the eleven Harrison's Special plants selected in 1951 from the almost-100%-infected commercial crop showed severe wilting in 1952. F2 and F3 progeny grown in 1953 and 1954 also exhibited severe symptoms indicating that these plants had initially escaped infection rather than possessing resistance.

Glasshouse Trials

Methods

In 1953, twenty-eight lines from the crosses previously described and sixteen species were grown in infected soil in 4-in. pots placed in trays in the glasshouse. Five plants of each line were inoculated with 4 ml per pot of a suspension of the fungus grown on oat grains. This was done twice during the growing season.

In 1954, eleven breeding lines, ten varieties, and two species were grown in infected soil in 4-in. pots embedded in sterilised sand in the glasshouse. Ten plants of each line were inoculated three times during the growing season by pouring 10 ml per pot of a suspension of the fungus cultured on chopped peas.

Results

No typical wilt symptoms developed in either year. In 1953, one plant of *N. fruticosa* and one plant of *N. petiolaris* showed wilting, but *V. dahliae* was not isolated from these plants. In 1954, *N. glutinosa* showed some slight wilting and yellowing of the leaves.

During both these seasons the maximum daily temperatures in the glasshouse during the summer months frequently exceeded 100°F. Supplementary applications of nitrogen, as nitrate of soda, resulted in good growth in both years. In 1953, the soil in the pots dried quickly and it was difficult to maintain a satisfactory water balance. Burying the pots in sand in 1954 gave much more uniform soil-moisture conditions.

Discussion

The field resistance shown by Amarello, TI 448 A, and Ky 34 was not transferred to the progeny of the crosses made, nor did the progeny of the eleven uninfected Harrison's Special plants selected in 1951 show any resistance to the disease. These results suggested that the eleven Harrison's Special plants had merely escaped infection, and that field resistance displayed by Amarello, TI 448 A and Ky 34 was controlled by multiple genes.

A serious impediment to the search for resistance was imposed by what may be termed the "stage-of-growth effect." Symptoms were never expressed until the plant was flowering, and in many cases plants had been flowering for some considerable time before any disease effects were visible. Thus late varieties gave a false appearance of being resistant, particularly in seasons when the onset of the disease did not occur until late February. Also, material selected and bagged early in the season was liable to develop symptoms at a later date.

Another difficulty was the seasonal effect of the degree of infection and the intensity of the expression of symptoms. In seasons when the disease was not severe, several adjacent plants would not show infection. Next season the progeny of these, instead of segregating for resistance, would all develop severe symptoms.

These difficulties led to the inclusion in the breeding material of many lines which had no field resistance and in some cases were more severely affected than the commercial variety, Harrison's Special.

The results achieved by growing material in heavily infected soil in the glasshouse showed no improvement over field methods and neither method permitted the handling of large numbers of plants, a prerequisite when dealing with material which does not show a very high level of resistance to disease.

In 1954 it was decided to discontinue field trials as a method of evaluating material for resistance to verticillium wilt and to try to develop a glasshouse method in which resistance could be measured in the seedling stage. The results of this work will be reported in another paper.

Acknowledgements

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THE GRAZING BEHAVIOUR OF DAIRY CATTLE IN RELATION TO MILK PRODUCTION, LIVE WEIGHT, AND PASTURE INTAKE

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Summary

Grazing behaviour observations were made on a mixed group of free-grazing Jersey and Friesian cattle throughout their lactation period.

These observations established that:

1. There was a positive, though small, relationship between both grazing and rumination times, milk production and pasture intake.
2. Differences in live weight had little effect on grazing and rumination time.
3. Where the fat-corrected milk (f.c.m.) production of the two breeds was the same, differences between them in grazing times were negligible.
4. The grazing time required per unit of pasture intake was appreciably greater in the Jerseys than the Friesians, whereas the feed intake required per lb of f.c.m. produced was greater in the Friesian than the Jersey.

Introduction

In an extensive series of studies at Ruakura, Hancock has sought to analyse the nature and magnitude of the variability observed in the grazing pattern of New Zealand dairy cattle. This work has been reviewed on several occasions (Hancock 1952, 1953). This paper is the final one in the series; its object is to report recent observations relating grazing behaviour to the variation in milk production, live weight, and pasture intake, recorded in a free-grazing herd of Jersey and Friesian cattle.

The characteristics of the New Zealand pastoral farming system together with the techniques used at Ruakura in recording grazing behaviour have been described in detail in earlier papers of this series. Suffice to state here that in this experiment grazing and ruminating activity were noted for each cow each $2\frac{1}{2}$ minutes throughout four 24-hour periods spaced at approximate three-day intervals throughout two successive weeks. Four such fortnightly observation periods were spaced throughout the lactation and timed to coincide with early spring, i.e. shortly following calving, late spring, summer, and autumn. Approximately 25 animals were under observation in each fortnight, these consisting of approximately ten Jersey, ten Friesian, and five non-lactating miscellaneous cows. The animals included varied slightly in each fortnightly period, though the majority of animals were common to each.

Pasture intake was estimated by the faecal chromium—marker nitrogen digestibility technique commonly used at Ruakura and described in detail in previous publications from this Station (Lancaster *et al.* 1953).

TABLE 1. GRAZING OBSERVATIONS, JERSEY-FRIESIAN GROUP
1st Period, October 14-28

	Age	C.D.	x1 Wt. (lb)	x2 FCM (lb/ fort-night)	z O.M. Intake kg/fort-night	y1 Grazing Time min/day	y2 Cudding Time min/day
Friesian	7	4/9	1240	737	242	497.5	380.0
	2	17/8	860	256	158	470.0	357.5
	6	22/7	1190	589	227	542.5	372.5
	3	9/8	940	309	145	377.5	407.5
	7	1/8	1190	787	255	492.5	372.5
	3	26/7	900	578	209	547.5	392.5
	6	2/8	1130	657	207	557.5	395.0
	4	20/7	1070	739	210	472.5	382.5
	6	19/7	1130	738	232	490.5	325.0
	8	10/8	1380	481	238	462.5	387.5
Jersey	3	29/7	880	270	157	432.5	380.0
	5	20/7	660	425	164	545.0	290.0
	3	19/7	920	554	237	435.0	390.0
	3	20/7	820	240	154	485.0	340.0
	2	5/8	670	77	104	415.0	290.0
	6	9/8	970	619	168	472.5	350.0
	6	1/8	870	274	148	487.5	372.5
	3	9/8	930	470	146	485.0	322.5
	3	25/8	790	18	127	425.0	375.0
Non-lactating	2	—	740	—	98	367.5	307.5
	3	—	—	—	135	415.0	362.5
	5	—	—	—	130	412.5	360.0
	3	—	—	—	130	402.5	312.5
	2	—	690	—	125	407.5	320.0

TABLE 2. GRAZING OBSERVATIONS, JERSEY-FRIESIAN GROUP
2nd Period, December 12-23

	Age	C.D.	x1 Wt. (lb)	x2 FCM (lb)	z O.M. Intake kg/fort-night	y1 Grazing Time min/day	y2 Cudding Time min/day
Friesian	7	4/9	1265	625	312	550	528
	2	17/8	920	167	182	490	423
	6	22/7	1250	461	278	563	480
	3	9/8	990	298	234	545	488
	7	1/8	1245	685	311	583	498
	3	26/7	940	521	252	598	465
	6	2/8	1180	548	286	565	505
	4	20/7	1095	597	287	563	490
	6	19/7	1175	665	284	553	440
	8	10/8	1445	315	278	518	483
Jersey	3	29/7	930	178	185	465	440
	3	19/7	948	502	278	538	510
	3	20/7	890	101	155	508	445
	6	9/8	945	475	235	570	445
	6	1/8	900	262	185	558	423
	3	9/8	960	357	191	588	420
Non-lactating	3*				191	435	430
	3*				145	498	433
	3*				181	463	433
	3*				178	428	418
	2		750		126	483	410
	3		860		149	455	468
	3*		940		160	510	408

* Three-day average for grazing observations.

TABLE 3. GRAZING OBSERVATIONS, JERSEY-FRIESIAN GROUP
3rd Period, February 3-17

	Age	C.D.	x1 Wt. (lb)	x2 FCM (lb)	z O.M. Intake kg/fort-night	y1 Grazing Time min/day	y2 Cudding Time min/day
Friesian	7	4/9	1220	446	242	535	553
	2	17/8	940	117	142	483	420
	6	22/7	1280	291	187	555	428
	3	9/8	1068	195	189	505	485
	7	1/8	1272	520	248	535	523
	3	26/7	970	378	191	510	495
	6	2/8	1155	440	254	508	568
	4	20/7	1060	434	256	543	468
	6	19/7	1230	475	250	540	453
	8	10/8	1480	195	233	423	485
Jersey	5	20/7	700	298	143	513	468
	3	19/7	960	345	229	468	540
	6	9/8	975	336	199	533	463
	6	1/8	920	169	171	508	453
	3	9/8	885	237		550	478
		17/8	690	162	160	598	453
Non-lactating	3	25/8	895			483	410
	2	23/7	863		125	483	480
	3	29/7	990			458	410
	2	12/8	655		136	620	420
	2	25/8	733		151	550	500
	3	20/7	930		137	468	460
	3	2/9	970			475	350
	2	5/8	810		199	435	403

Silage feeding included in O.M. intake and in grazing and cudding time.

TABLE 4. GRAZING OBSERVATIONS, JERSEY-FRIESIAN GROUP
4th Period, April 14-28

	Age	C.D.	x1 Wt. (lb)	x2 FCM (lb)	z O.M. Intake kg/fort-night	y1 Grazing Time min/day	y2 Cudding Time min/day
Friesian	7	4/9	1245	367	220	625	260
	6	22/7	1295	18	165	500	273
	3	9/8	1065	80	146	475	165
	5	22/8	1320	172	209	535	213
	3	26/7	960	233	127	463	260
	6	2/8	1200	222	204	565	260
	4	20/7	1145	294	180	545	268
	8	10/8	1463	98	177	460	238
Jersey	5*	20/7	700	247	126	635	165
	3*	19/7	960	247	169	448	253
	6	9/8	980	93	160	495	228
	6	1/8	885	69	106	370	143
	3	9/8	900	167	121	518	195
	3	25/8	860	Dry	108	430	240
Non-lactating	2	23/7	872		96	470	208
		17/8	700			600	205
	2	12/8	670		106	525	228
	2	25/8	740		123	565	248
	2	17/8	950		118	478	268
	6	19/7	1285		183	490	240
	3	29/7	1020		139	395	203
	3*	20/7	960		98	485	268
	3	2/9	950		94	395	193
	2	5/8	825		80	383	225

* 3-day grazing average only.

RESULTS

Tables 1–4 summarise the information available for each animal in each of the four periods. Milk yield was recorded as the total amount of fat-corrected milk (f.c.m.) obtained during the fortnight, pasture intake was expressed as kilogrammes of organic matter consumed in the fortnight, while grazing and ruminating times were tabulated as the average 24-hour figure based on the four 24-hour observations in each fortnight.

As indicated in the introduction, the two major points of interest which the experiment was planned to clarify were:

(a) The relationship between grazing and ruminating times and pasture intake.

(b) Possible differences in the grazing pattern associated with breed type.

TABLE 5. RELATIONSHIP BETWEEN GRAZING TIME (y1), RUMINATING TIME (y2), AND F.C.M. (x2)

	Means		b	c	m.s.	Means		b	c	m.s.
	y1	x2				y2	x2			
Period I										
(a) Friesians (10)	491	587	0.14	408	2,316	377	587	—0.03	395**	560
(b) Jerseys (9)	465	327	0.09	435	1,598	346	327	0.01	341**	1,636
Total (19)	479	464	0.11*	428	1,777	362	464	0.04	346**	1,167
Period II										
(a) Friesians (10)	553	488	0.13*	488	468	480	488	0.08	442**	855
(b) Jerseys (6)	538	313	0.17	483	1,555	447	313	0.10	416	1,008
Total (16)	547	422	0.13**	491	746	468	422	0.11*	422**	846
Period III										
(a) Friesians (10)	514	349	0.18*	452	1,001	488	349	0.19	421**	1,905
(b) Jerseys (6)	528	258	—0.33	613	1,515	476	258	0.26	410**	804
Total (16)	519	315	0.06	499	1,639	483	315	0.19	422	1,337
Period IV										
(a) Friesians (8)	521	186	0.36*	455	1,858	242	186	0.12	220**	1,344
(b) Jerseys (5)	493	165	0.71	377	8,019	197	165	0.18	168(*)	2,391
Total (13)	510	178	0.44*	432	3,539	225	178	0.15	198	1,893

Note: b = regression of y1 (y2) on x2.
c = adjusted mean
m.s. = mean square.

Both problems were investigated by covariance analysis of the data.

Table 5 summarises the results of such an analysis in which the f.c.m. yield was regarded as the independent variable. The regression of grazing and ruminating time on milk yield was positive throughout, although the regression coefficient was not always significantly greater than zero in each period.

Differences between the two breeds in the regression coefficients could not be established because of the limited numbers involved. Even so, it is interesting to note that throughout each period and each analysis the regressions of grazing and cudding times on the variables considered were usually greater in the case of the Jerseys than in the case of the Friesians. For this reason, then, the individual breed regressions rather than the pooled within-group regressions have been used in correcting means.

The comparison of grazing and ruminating times for the Jersey and Friesian groups when f.c.m. production was regarded as constant failed to reveal clear-cut differences between the two breeds in their grazing time. However, the rumination times of the Friesians tended to be about 10% larger than those of the Jerseys.

This analysis was then extended to one in which both f.c.m. and live weight were regarded as joint independent variables. The results of this analysis (Table 6) indicated little relationship between live weight and the grazing time when f.c.m. production was regarded as constant. But as with the initial analysis (Table 5) the regression of grazing time on f.c.m. when live weight was constant was found to be usually significant. Rumination time exhibited little relationship to f.c.m. production. On the other hand, there was a suggestion that live weight had a somewhat greater influence on rumination time than on grazing time.

When live weight and pasture intake were regarded as the joint independent variables it was again obvious that live weight barely influenced the grazing pattern (Table 7). On the other hand, the relationship between pasture intake and the grazing pattern was somewhat greater. These data also suggested that, in order to achieve a pasture intake comparable with that of a Friesian, the Jersey animal required to spend longer in grazing than the Friesian. This conclusion is also in agreement with that suggested by the data listed in Table 6, which indicated that the grazing time (but not the cudding time) per unit of f.c.m. production was greater in the Jersey than the Friesian.

The final analysis (Table 8) substantiated the relationship between pasture intake and f.c.m. production, and illustrated that the Friesian animal requires a greater feed intake per unit of f.c.m. produced than does the Jersey.

TABLE 6. RELATIONSHIP OF GRAZING (y1), RUMINATING TIMES (y2) TO LIVE WEIGHT (x1) AND F.C.M. (x2)

	Mean			b1	b2	c	m.s.	Mean	b1	b2	c	m.s.
	x1	x2	y1					y2				
Period I												
(a) Friesians (10)	1103	587	491	—0.04	0.16	442	2,604	377	0.01	—0.04	384	635
(b) Jerseys (9)	834	327	464	—0.22	0.16	596	1,350	345	0.33*	0.09	102	769
Total (19)	976	464	478	—0.07	0.15*	473	1,798	362	0.12*	0.04	262	936
Period II												
(a) Friesians (10)	1151	488	552	—0.05	0.15*(*)	538	457	480	0.07	0.06	368	809
(b) Jerseys (6)	929	312	537	—0.25	0.21	700	2,040	447	—0.37	0.15	747	1265
Total (16)	1067	422	547	—0.05	0.16**	459	730	467	0.077	0.07	355	765
Period III												
(a) Friesians (10)	1168	349	513	—0.08	0.19*	538	943	487	0.03	0.19	386	2144
(b) Jerseys (6)	855	257	528	—0.12	—0.25	698	1,671	475	0.05	0.23	377	1022
Total (16)	1050	314	519	—0.10	0.13	579	1,355	483	0.01	0.19*	415	1435
Period IV												
(a) Friesians (8)	1212	185	521	0.12	0.40*	296	1,739	242	0.05	0.14	155	1530
(b) Jerseys (5)	885	164	493	—0.45	0.45	813	8,033	196	0.39	0.4	—218	462
Total (13)	1086	177	510	0.04	0.45*	391	3,822	244	0.12	0.18	57	1252

b1 = regression of y1 (y2) on x1 independent of x2
b2 = regression of y1 (y2) on x2 independent of x1
c = adjusted mean
m.s. = mean square.

TABLE 7. RELATIONSHIP OF GRAZING (y1) AND RUMINATING TIMES (y2), TO LIVE WEIGHT (x1) AND O.M. INTAKE (z)

	Means			b1	b2	c	m.s.	Mean y2	b1	b2	c	m.s.
	x1	z	y1									
Period I												
(a) Friesians (10)	1103	212	491	—0.21	1.49	402	2075	377	0.06	0.40	394	578
(b) Jerseys (9)	834	156	464	—0.10	0.30	497	2151	345	0.19	0.21	150	1008
Total (19)	975	185	478	—0.08	0.75	419	2023	362	0.09	0.01	275	975
Period II												
(a) Friesians (10)	1150	270	552	—0.17	0.96**	482	340	480	—0.11	0.60	329	578
(b) Jerseys (6)	928	204	537	—0.61	0.04	39	2818	447	—0.51	0.79	758	486
Total (16)	1067	245	547	—0.10	0.58*	511	1046	467	—0.02	0.60**	343	469
Period III												
(a) Friesians (10)	1167	219	513	—0.11	0.44	542	1537	487	—0.05	0.87	356	1901
(b) Jerseys (5)	849	180	524	—0.17	0.19	698	2852	475	—0.18	1.45	364	676
(c) Dry (5)	798	149	511	—0.59	—1.31	1180	442	452	0.07	—0.78	516	2103
F, J only	1061	206	517	—0.10	0.28	563	1622	483	—0.07	0.94*	364	1261
F,J,D (20)	995	192	515	—0.19	0.24	567	2348	475	0.01	0.54	379	1629
Period IV												
(a) Friesians (8)	1211	178	521	—0.21*	2.08**	399	445	242	—0.00	0.22	207	1814
(b) Jerseys (6)	880	131	482	—0.88	2.27	957	4155	204	0.15	0.71	—17	1774
(c) Dry (9)	919	115	465	—0.33	1.87	548	2596	231	—0.02	0.23	226	951
F,J only (14)	1086	162	510	—0.25(*)	2.13**	433	3176	224	—0.04	0.43	113	1520
F,J,D (23)	1010	141	489	—0.27**	1.99**	479	2655	227	0.03	0.18	171	1319

b1 = regression of y1 (y2) on x1 independent of z
b2 = regression of y1 (y2) on x1 independent of x1
c = adjusted mean
m.s. = mean square

TABLE 8. THE RELATIONSHIP OF O.M. INTAKE (z) TO F.C.M. PRODUCTION (x2)

	z	x2	b	c	m.s.
Period I					
(a) Friesians (10)	212	587	0.16**	119	462
(b) Jerseys (9)	156	327	0.13**	113	689
Total (19)	185	464	0.17**	108	577
Period II					
(a) Friesians (10)	270	488	0.19**	178	481
(b) Jerseys (6)	204	312	0.25**	126	412
Total (16)	245	422	0.25**	142	590
Period III					
(a) Friesians (10)	219	349	0.22**	142	647
(b) Jerseys (5)	180	262	0.27	123	1034
Total (15)	206	320	0.25**	127	725
Period IV					
(a) Friesians (8)	178	185	0.12	155	964
(b) Jerseys (5)	136	164	0.11	118	854
Total (13)	162	177	0.14	137	1194

b = regression of z on x2
c = adjusted mean
m.s. = mean square.

DISCUSSION

The conclusions to be drawn from this experiment may be simply stated as follows:

1. There was a positive relationship between grazing time and intake, between grazing time and f.c.m. production, between cudding time and intake, and between cudding time and f.c.m. production.
2. The grazing time required per unit intake of pasture was appreciably greater in the Jerseys than in the Friesians, whereas the feed intake required per lb of f.c.m. produced was greater in the Friesian than the Jersey.
3. When the f.c.m. production of the two breeds was the same, differences between them in grazing times were negligible. The Friesian animals, however, tended to have a somewhat greater rumination time.

Some comment on these conclusions may perhaps be worthwhile.

Assuming the net energy requirement per lb of f.c.m. produced from either the Jersey or Friesian breed is the same, it is only to be expected that a small animal will require to spend longer in obtaining sufficient pasture to produce this lb of f.c.m. than will a larger animal. On the other hand, the larger animal has a greater maintenance requirement

than the small animal. The consequence of this is that where the Friesian and Jersey are producing the same amount of milk energy the feed intake requirement per unit of f.c.m. produced is greater in the case of the Friesian than the Jersey, which in turn leads to a lengthening of the grazing period. The net effect of these two counterbalancing situations underlies the conclusion that where f.c.m. production is equivalent Jersey and Friesian animals graze for a similar period of time.

A further point worthy of mention is the relatively small degree of relationship established within a breed between pasture intake and rumination time. In a series of indoor feeding trials Hancock (1954) demonstrated a strong relationship between these two variables. He also observed that the crude-fibre content of the feed had a marked effect on rumination time. Presumably then, the rather small relationship observed between intake and rumination times observed in this experiment reflects the operation of selective grazing.

The data reported here also exhibit the usual seasonal fluctuations in the grazing pattern which may be attributed to changes in pasture quality. These seasonal fluctuations have been described in detail in the previous papers of this series (see Hancock 1954).

ACKNOWLEDGEMENTS

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THE ASSOCIATION OF *Phytophthora* spp. WITH MORTALITY OF *Pinus radiata* AND OTHER CONIFERS

I. SYMPTOMS AND EPIDEMIOLOGY IN SHELTERBELTS

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Summary

A serious disease of *Pinus radiata, P. muricata, Cupressus macrocarpa, Chamaecyparis lawsoniana,* and other conifers, has been killing large numbers of mature shelter and ornamental trees in various parts of New Zealand.

Trees die rapidly within a space of 1–3 months or defoliate heavily and remain in a short tufted-needle condition over a period of years.

Primary symptoms appear to be confined to death of feeding rootlets.

Isolations from soil, using apple fruit as a selective medium or "trap", yielded *Phytophthora* spp. in large quantities. An apple-trap method was used for surveys of *Phytophthora* distribution since the fungi could rarely be isolated directly from rootlets before invasion by saprophytes. *P. cinnamomi* and *P. cactorum* were the species most commonly recovered. *P. citricola, P. syringae, P. cryptogea,* and *Pythium* spp., were also isolated from soil below diseased trees. Pathogenicity has been demonstrated so far for the first two.

There was a highly significant correlation between presence of *Phytophthora* spp. and disease symptoms in shelterbelts, and a significant correlation between severity of external symptoms and abundance of *Phytophthora* spp. in the soil. Some originally healthy-looking shelterbelts growing in soil heavily infected with *Phytophthora* spp. developed severe symptoms later, following an exceptionally wet autumn, winter, and spring.

The disease was present on some well drained soil types as well as being prevalent on heavy soils with poor drainage.

The efficiency of the isolation techniques used is examined in some detail in order to assess the value of the data obtained in surveys for *Phytophthora* in soils.

P. cinnamomi was isolated from depths up to two feet.

Phytophthora populations were found to be concentrated mainly in the rootlet zones of trees, being isolated rarely under pasture in adjacent open fields.

Phytophthora spp. may persist in soil for at least two years after death of trees.

P. radiata is highly susceptible as seedlings and up to 4–5 years of age. Trees are then resistant until the mature phase of growth is reached at age 20-30 years.

Continual heavy rain is more important than poor soil drainage alone in the maintenance of soil moisture conditions suitable for *Phytophthora* infection.

Epidemics occurred only in years in which there was abnormally early re-wetting of the soil in autumn, with wet conditions continuing until spring. Prior summer drought may have contributed to epidemic development in some instances by causing fragmentation of heavy soils,

thus assisting re-wetting in autumn. Drought alone was not a cause of death during the period for which weather records are available.

It has been shown experimentally that *P. radiata* has a very great capacity for rootlet regeneration following severe damage from drought, flooding, or *Phytophthora* infection. Flooding can kill roots, but at only a fraction of the rate of destruction by a combination of *Phytophthora* and flooding.

Phytophthora spp. when present intensify rootlet mortality to many times that which normally occurs in winter. This rootlet loss would be made good by regeneration in most seasons in time to support spring growth. Symptom expression is seen to depend on destruction of the balance between transpiration demand and absorptive capacity of the root system: if rootlet mortality is heavy in autumn and winter and continues into spring because of excessive soil moisture, trees suffer from physiological drought at a time when their water demand is rising rapidly. Full-crowned trees with a large transpiring surface rapidly reach a state of permanent wilt and die. Where the attack is less severe, trees defoliate heavily and new growth of needles and shoots is much reduced; with their now-reduced transpiring surface they can tolerate severe rootlet damage and may behave as though resistant.

The main difference between the disease of pines in New Zealand shelterbelts and little-leaf disease of *P. echinata* (involving *P. cinnamomi*) in forests of the south-eastern U.S.A. is one of rapidity of symptom development. This could be explained by different transpiration demands of full- and reduced-crowned trees. The two diseases are considered to be basically the same.

Phytophthora spp. have been isolated from several commercial *P. radiata* forests in the North Island. The situation there is more complex and will be the subject of later reports.

Manurial treatments and improved drainage are likely to have limitations as a control measure. Large-scale applications of fungicides to soil is impracticable, and breeding or selection for resistance to all *Phytophthora* spp. involved would be a very long-term project.

The most satisfactory answer to the problem involves a change from the almost traditional use of *P. radiata, P. muricata, C. macrocarpa,* and *C. lawsoniana* to species found to be locally suitable and resistant to *Phytophthora* attack.

INTRODUCTION

Epidemic deaths of *Pinus radiata* Don occurred in spring and summer 1953–54 and 1956–57, two exceptionally wet seasons. Considerable numbers of mature trees died suddenly in shelterbelts, farm woodlots, golf courses, and gardens in various parts of the country, particularly in the North Island (Fig. 1).

The most severely affected areas were adjacent to Auckland and throughout the North Auckland Peninsula, while less frequent but often severe attacks occurred elsewhere, e.g. Manawatu and Wairarapa districts.

Early in 1957 a survey* of the North Auckland Peninsula showed that mortality or severe defoliation was present on 55% (869 out of 1,570) of sites on which *P. radiata* was growing; trees were affected singly

* Survey carried out in conjunction with C. F. Sutherland, Soil Bureau, and J. Levy, N.Z. Forest Service.

Fig. 1.—Typical example of affected shelterbelt—35-year-old *P. radiata*, Whenuapai.

or in groups of up to 50 or more. A further 16% were slightly affected. According to local reports there had been outbreaks of a minor but similar nature in 1924, 1937, and 1946, in addition to those of 1953 and 1956. Outbreaks also occurred in parts of the South Island during spring and summer 1957–58, following an abnormally wet winter.

Cupressus macrocrapa Hartw., *Chamaecyparis lawsoniana* (L.) Parl., *P. muricata* Don, and *P. pinaster* Sol. are often affected in a similar manner to *P. radiata*.

Because of its rapid growth and tolerance of a wide range of soils and climate, *P. radiata* has become one of the commonest trees used for farm shelter in New Zealand. Deaths have rendered some shelterbelts useless and opened large wind gaps in others, posing a problem in replacement.

Loss of shelterbelt trees is of considerable importance in farm management but of even greater concern has been the possibility of similar losses occurring in neighbouring commercial plantations of *P. radiata*.

In the United States, Campbell (1948, 1951), Campbell and Copeland (1954), and others, described a disease of short-leaf pine (*P. echinata* Mill.), little-leaf disease, in which rootlets were attacked by *P. cinnamomi* Rands. Under conditions of poor internal soil drainage, damage was sufficiently severe for trees to deteriorate; needles became short, somewhat yellowed, sparse, and tufted on ends of twigs. Trees died within 3–10 years of first showing symptoms.

Phytophthora cinnamomi was isolated from roots of dying *C. lawsoniana* in two Waikato shelterbelts in 1952.

Using "trapping" techniques similar to that used by Campbell, *P. cinnamomi* was recovered with striking regularity from soil beneath diseased *P. radiata* near Auckland in 1953 and 1954. Later, other species of *Phytophthora* were also isolated from soil beneath affected pines and cypresses.

The following account discusses the association of *Phytophthora* spp. with dying *P. radiata* and other conifers, mainly in shelterbelts in the Auckland district. Information gained from these studies has been of benefit in investigations of mortality in forest areas, the outcome of which will be described separately.

SYMPTOMS

Healthy *P. radiata* trees in single-row shelter belts on well top-dressed farms have crowns down to ground level or grazing height. Needles are dark green, 5–7 in. long, and are retained for 3–4 seasons.

Above-ground symptoms of the disease are purely secondary and vary considerably depending on such factors as severity of attack, time of season, and age and previous condition of tree.

First observable symptoms are that needles become dull and droop slightly from the base. This may occur any time after midwinter (July). Needles then die back from the tip at a more or less uniform rate for all needles on a tree, although sometimes those of the upper crown and ends of branches die more slowly than the rest. New shoots sometimes emerge following death of all previous season's needles. They are usually delayed by comparison with normal spring growth and, with the exception of some trees on well drained soil (e.g. Canterbury Plains alluvium) die rapidly after making from one to several inches of growth.

The sudden reddening of foliage and death of trees within the space of a few weeks is the commonest and most characteristic form of the disease.

Sometimes, however, affected trees do not die but suffer abnormally heavy needle fall. The whole crown may be affected, defoliation may be restricted to one side of the tree, to the lower branches, or more rarely to the upper crown. Needle die-back occurs as before but the colour of dead needles varies and may be dull brown, yellow, or brick-red. New season's growth may be normal but is usually much reduced in both shoot growth and needle length. Affected trees appear thin-crowned with short needles tufted on ends of twigs (Fig. 2). They may deteriorate further and die during the summer or they may recover, but more frequently they stay in this condition for several years. In this case their appearance and gradual decline is similar to that of trees suffering from little-leaf disease of *P. echinata* in the south-eastern United States.

Fig. 2.—Part of 36-year-old shelterbelt (Plot 21, Table 1) in which heavy defoliation changed trees from a normal to a "littleleaf" condition in a space of three months. Deaths occurred elsewhere in the row.

Photo: J. W. Endt.

Affected trees are apparently free from major attacks by any pathogen above ground although there may be an increase in the amount of twig die-back. There are no trunk cankers and no signs of bark-beetle attack on partially affected trees until some months after death. Although needle-infecting fungi may become established on weakened or dead needles, the etiology of needle death is characteristic of a physiological die-back affecting the whole tree or major parts of it rather than primary needle-blight attack. Main roots are sound, but there is a dearth of healthy rootlets as compared with adjacent healthy trees.

Symptoms are confined almost entirely to trees over 20 and particularly over 30 years of age.

Similar symptoms are to be seen on other *Pinus* spp. With cypresses, whole trees may redden and die or, in the slower form of attack, trees may defoliate progressively from the bases of all branches and twigs towards the tips.

Isolations

The difficulties of isolating *Phytophthora* spp. from infected tissue are well recognised. In the case of little-leaf disease of *P. echinata*, Siggers and Doak (1940) and Campbell (1948, 1951) found that isolations yielded mainly saprophytic micro-organisms. Local results with *P. radiata* were similar, the commonest isolate being *Trichoderma viride* Pers. ex Fr. The only pathogen recovered was *P. cinnamomi* and

this was isolated only rarely from diseased rootlets. It was obvious that direct isolation was impracticable as a method for large-scale quantitative studies on *Phytophthora* distribution in diseased shelterbelts or forest areas.

Isolation from the soil by most described techniques would appear to be no easier than from diseased tissue, *Phytophthora* spp. being noticeably absent from lists of fungi obtained in soil studies, despite their widespread distribution as shown by pathogenic behaviour. The two most successful isolation methods would appear to be Campbell's (1949) modification of Tucker's (1931) apple-trap technique and Anderson's (1951b) use of pineapple leaf bases suspended in water over infected soil. In contrast to apples, pineapple leaves are not readily obtainable locally, nor are they known to be as susceptible as apples to such a wide range of species of *Phythophthora*.

Slight modifications to Campbell's method were made after its first use when it was found difficult to wet summer-dry soils after these had already been placed in holes in apples. Soil samples were therefore saturated first in the collecting jars. It was found too that better results were obtained by soaking soil for two days before inserting into apples (Newhook 1958).

The standard isolation procedure used to obtain most of the results described below was as follows:

A square foot of litter or of turf to a depth of approximately two inches was removed from the surface of a sample site and the next four inches in depth chopped with a spade to sever roots. Soil was well mixed by trowel before filling a numbered four-ounce jar. Implements were sterilised by wiping with alcohol between sample sites. At the laboratory, jars were topped up with tap water and left to stand for approximately forty hours. Apples were wiped with alcohol and drilled to a depth of 2–2½ inches with a ½ inch wood drill (with point and wings shortened) in a low-speed electric drill. Holes in two apples were almost filled with wet soil from each sample jar and sealed with a liberal application of petroleum jelly. Apples were placed in numbered wraps and incubated for between two and three weeks. At the end of this time isolations were made from all likely-looking internal or external rots. All firm rots were cultured since it was impossible otherwise to distinguish between the various *Phytophthora* spp. and between them and some firm saprophytic rots. *P. cinnamomi* and *P. cactorum* (Leb. et Cohn) Schroet. were the commonest species of *Phytophthora* isolated. Others included *P. citricola* Sawada, *P. syringae* (Berk.) Kleb., and *P. cryptogea* Pethybr. et Laff. *Pythium* spp. were isolated occasionally from some sampling areas.

In addition to the apple-injection technique two other methods using apples were tested:

1. Undamaged apples were placed in tins containing soil covered by ¼–½ in. of tap water and examined periodically for rots.

TABLE 1.—RELATIONSHIP BETWEEN EXTERNAL DISEASE SYMPTOMS AND *Phytophthora* ISOLATIONS FROM SOIL SAMPLES. ALL TREES *P. radiata* OVER 30 YEARS OF AGE

Plot No.	Location	Soil Type	Disease Severity	% Soil Samples Infected with		Total % Infected Samples
				P. cinnamomi	Other *Phytophthora* spp.†	
1	Redoubt Rd.	34aH	xx	25	91	97
2	Dairy Flat	47	xxxx	63	10	70
3	Redoubt Rd.	34aH	xxxx	25	44	66
4	Whenuapai	72a/45	xxxx	65	0	65
5	Whenuapai	72a/45	xxx	57	4	61
6	Flat Bush Rd.	34aH	xxxx	37	37	60
7	Waimauku	45	xxx	50	5	55
8	Whenuapai	72a/45	xxxx	55	0	55
9	Whenuapai	72a/45	xxxx	49	10	54
10	Whenuapai	72a/45	xxx	29	22	49
11	One Tree Hill	95	xx	0	48	48
12	Massey	83	xx	33	5	38
13	Waimauku	45	xx	30	5	35
14	Redoubt Rd.	34aH	xxxx	5	26	30
15	Western Springs	73	xxxx	30	0	30
16	Sth. Motorway	72c	xx	0	26	26
17	Whenuapai	72a/45	xx	25	0	25
18	Coatesville	72a/45	xx	0	15	15
19	Sth. Motorway	95	x	0	10	10
20	Whenuapai	72a/45	Outwardly healthy when sampled, later xxx, xx, x	*30 **26	16 63	36 66
21	Whenuapai	72a/45		37	7	44
22	Coatesville	72a/45		6	17	23
23	Flat Bush Rd.	34aH	Outwardly healthy	30	0	37
24	Redoubt Rd.	34aH	" "	0	34	34
25	Whenuapai	72a/45	" "	30	1	31
26	Sth. Motorway	72c	" "	0	14	14
27	Pt. Chevalier	73	" "	11	6	14
28	Whenuapai	72a/45	" "	3	10	13
29	Whenuapai	83	" "	4	2	6
30	Riverhead	45	" "	2	2	4
31	One Tree Hill	95	" "	0	3	3
32	Mt. Eden	95	" "	0	3	3
33	Potters Park	73	" "	0	3	3
34	Huapai	45	" "	0	2	2
35	Mt. Eden	95	" "	0	0	0
36	Coatesville	72a/45	" "	0	0	0
37	Huapai	45	" "	0	0	0

† Mainly *P. cactorum* but *P. citricola, P. syringae,* and other *Phytophthora* spp. also present in some plots.

* Data obtained by apple-injection method when plot first sampled and apparently healthy, Jan. 1956.

** Figures are aggregates from three sampling methods on same sites; Sep. 1956, after severe symptoms appeared.

N.B.—Soil samples yielding more than one *Phytophthora* sp. were scored only once in determining total percentages for final column.

Key to scale of disease severity

xxxx Most trees dead in sampling plot.

xxx Few or no trees dead but most with severe abnormal needle fall leading to "thin" crowns with short tufted needles and some twig or branch die-back.

xx A few trees in plot dead or with severe defoliation, remainder apparently healthy.

x No mortality, a few trees with excessive needle fall compared with other trees in row.

Key to soil types

(ref. *N.Z. Soil Bur. Bull. n.s. 5*)

34aH Brookby clay loam, hill phase; from sandstone; fair drainage.
45 Waikare clay; from claystone; subsoil poorly drained.
47 Wharekohe silt loam; from silicious claystone; poorly drained.
72a Otao fine sandy loam; water sorted volcanic ash; subsoil fairly well drained.
72c Papatoetoe silt loam; water sorted volcanic ash; drainage fair to good.
73 Waitemata complex; water sorted ash, peat, sandstone; soil drainage often poor.
83 Hamilton clay loam; water sorted volcanic ash; well drained.
95 Ohaeawai silt loam and stony silt loam; from basalt; well drained.

2. Undamaged apples were buried amongst the fibrous root systems of trees and examined periodically until rots developed.

The apple-injection method was found to be the most satisfactory single method for all-the-year-round survey purposes, though there were definite limitations to its efficiency.

STUDIES ON *Phytophthora* DISTRIBUTION

Comparison of Diseased and Healthy Shelterbelts

Table 1 summarises the results of surveys, using the apple isolation technique, of the occurrence of *Phytophthora* spp. in soil beneath diseased and outwardly healthy shelterbelts within a radius of 20 miles of Auckland City.

(a) It appeared obvious that the diseased group (Nos. 1–19) had significantly higher fungus readings than the healthy group (Nos. 23–37), but to test this the percentages were ranked from 1 to 34 in order of size, from lowest to highest and the significance of the grouping (1–19 and 23–37) determined. The probability of a chance partition as extreme as the one shown (i.e. with hardly any overlapping), calculated from all possible partitions of 34 into two groups of 19 and 15, is 0.0000022 (approximately 2 in a million). Thus there is no doubt as to the significance of the association between presence of *Phytophthora* spp. and disease symptoms.

(b) Despite limitations in efficiency of the isolating technique (see later) and the fact that disease expression is related not only to presence of pathogenic *Phytophthora* spp. but also to environmental factors, there is a general correlation between relative severity of external

symptoms (column 4) and relative abundance of *Phytophthora* spp. in the soil (final column). To analyse the relationship, a coefficient of rank correlation (Kendall's tau) was calculated, ranking the percentages from 1 to 19. Its value was 0.45 and its significance 0.02.

(c) Out of six originally healthy-looking shelterbelts which yielded high figures for *Phytophthora,* severe symptoms developed in three (Nos. 20, 21, 22) after the exceptionally wet autumn, winter, and spring of 1956 when over 30 in. of rainfall above average was recorded. It may be significant that two others (Nos. 23, 24) in the midst of badly affected areas, were on the side of very steep gullies and may therefore have benefited from particularly good drainage.

(d) The disease occurred on all soil types investigated including both poorly drained clays (soil types* 45, 47) and well-drained volcanic soils (types 83, 95). This aspect is more fully borne out by results of the survey of Northland mentioned earlier, to be published separately.

(e) *P. cinnamomi* and *P. cactorum*, the two most commonly isolated pathogens, appeared to be of almost equal importance.

Distribution of Phytophthora *spp. in Relation to Root Systems of Trees*

Distribution in Depth. Samples were taken from successive 6-in. layers from carefully cleaned sides of ten 24-in. deep pits in a region of a badly diseased shelterbelt (plot 9†) from which *P. cinnamomi* had been consistently isolated. The two uppermost layers were friable loam (soil type Otao, 72a) with large numbers of feeding roots. The two lower layers were heavy yellow mottled clay (Waikare, 45) very compact, with columnar fracturing in which feeding roots were mainly restricted to flattened masses between interfaces of the clay columns. Samples in the latter case consisted of the more friable material of the interfaces rather than the compact clay itself.

The number of pits (out of ten) yielding *P. cinnamomi* at the depths indicated was as follows:

1–6 in. :	10	12–18 in. :	5
6–12 in. :	9	18–24 in. :	4

Thus the fungus may be present to a considerable depth, even in heavy subsoils where pine roots have penetrated.

Distribution in Relation to Root Spread and Symptoms. Four diseased shelterbelts were sampled on six occasions by what will be referred to as a "grid sampling" system. Soil from the 2–6 in. layer was taken from sample sites at regular spacings in parallel rows at increasing distances from the trunks. The first row and usually the

* Names and numerical symbols of all soil types referred to are taken from *N.Z Soil Bureau Bulletin n.s. 5.*

† Plot numbers in text refer to sampling plots listed in Table 1.

second were within the zone of prolific feeding rootlets which corresponds roughly to the region of branch overhang. The second or third was just beyond this while the others were well out into the open field, away from all pine roots.

Basically similar results were obtained from all six grids, four of which are depicted in Fig. 3, which represents diagrammatically the distribution of tree symptoms and *Phytophthora* isolations obtained on part of a farm property at Whenuapai. The field is approximately 180 × 100 yards and trees were 35 years old when first deaths occurred in 1953.

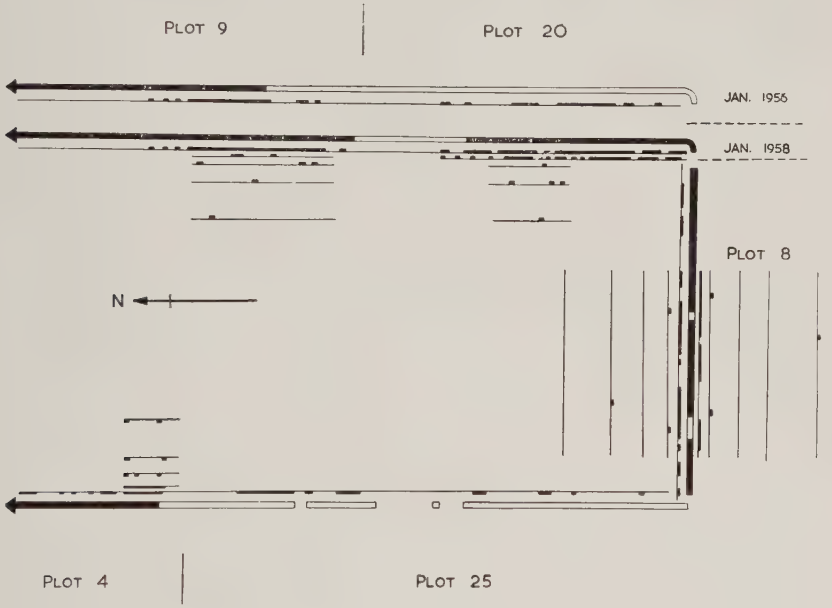


Fig. 3.—Relationship between *Phytophthora* distribution and symptoms in rows of 35-year-old *P. radiata* surrounding part of a property at Whenuapai.

Plot numbers refer to sampling plots in Table 1.

Key:
- Healthy trees.
- Dead and diseased trees.
- *Phytophthora* spp. isolated from soil samples.
- *Phytophthora* spp. not isolated.

It will be seen from the figure that *Phytophthora* spp. were isolated abundantly from the rootlet zones of all affected and some outwardly healthy portions of the shelterbelt system. Their frequency fell off immediately beyond the root zone to a very low level. Allowing for limitations in efficiency of technique there was a good correspondence between outward symptoms and *Phytophthora* distribution. In the south-east corner, (plot 20), are shown successive stages of part of the

shelter system which was outwardly healthy, though the soil was heavily infected, prior to spectacular deaths occurring in spring 1956.

Similar correlations between symptoms and distribution of *Phytophthora* were obtained from other plots.

Relationship between Sampling Data and Actual Phytophthora *Populations.*

Although use of the apple technique has disclosed a highly significant relationship between presence of *Phytophthora* and disease, the percentages of samples found to be infected were not always as high as expected from symptom expression. Also there were occasional moderately large apparent gaps in the distribution of *Phytophthora* spp. beneath diseased trees, as shown by isolation from soil samples.

It was necessary, therefore, to check on the limitations of the technique, so that some idea could be obtained of the extent to which negative results should in fact have been positive.

Size of Sample. Most of the data presented in this paper were obtained from a series of samples, each of approximately 4 oz, collected from a single row of 1-sq.-ft sample sites 3 to 6 ft apart on one side of a shelterbelt. Allowing an average branch overhang of 16 ft each side with corresponding feeding root distribution and without taking into account depth of root run, the samples represent only 0.5–1% of the areas examined.

Some variability of results must be expected on this account.

Failure of Phytophthora *to Infect Apples.* It is probable that for much of the year *Phytophthora* spp. are present in soil only in a resting stage, e.g. oospores and chlamydospores; Blackwell (1943) has pointed out that *Phytophthora* oospores may be very resistant to attempts to make them germinate. In the absence of mycelium, failure of oospores to germinate would mean that results obtained would be lower than theoretical.

Susceptibility of *Phytophthora* spp. to competitive micro-organisms in the sample may also account for a considerable amount of non-infection of apples. There is evidence for such loss by competition:

1. Despite being well mixed, an infected soil sample does not necessarily infect all apples inoculated with it.

2. Although apple tissue is highly selective as a trapping medium, there are other fungi besides *Phytophthora* spp. which will cause a rot. Some of these, such as species of *Mucor, Rhizopus,* and *Penicillium,* infect apple tissue more rapidly than most *Phytophthora* spp. and produce a soft rot which masks the typical firm rot of the latter. These saprophytic fungi are very frequent in some plots. *Trichoderma viride* produces a firm rot in apples and is probably the fungus most consistently isolated in using the apple technique. Its antagonistic properties are well known and although separate rots caused by *Trichoderma* and *Phytophthora* are commonly met with in the same apple, it is likely

that in other instances potential *Phytophthora* infections are prevented. Unrecognised antagonists may cause similar losses.

An illustration of how potential *Phytophthora* infection of apples might be lost was provided by an experiment using soil with a high degree of natural infection with *P. cinnamomi*. It was injected into apples alone and mixed 1:1 and 4:1 with soil recovered from test apples which had rotted with *Penicillium expansum* Link., a common isolate from soil from some areas. *P. expansum* completely prevented isolation of *P. cinnamomi* from the mixed samples.

Number of Apples per Soil Sample. Since *Phytophthora* spp. may not be isolated successfully from every apple inoculated with a single infected soil sample, to obtain the best possible results a large number of replications should be used in each case. There are practical limits to this procedure however. After early tests using three apples per sample, it was felt justifiable to cover more ground at the expense of a few successful isolations by using only two apples per sample.

On this account plot data are likely to underestimate the actual *Phytophthora* populations.

Effect of Sample Frequency on Plot Data. While an arbitrary minimum of 30 samples per plot was decided upon for the surveys, most plots in fact had between 33 and 50 samples. While the results obtained showed highly significant differences between diseased and healthy plots they nevertheless give only an approximation to the actual *Phytophthora* populations. The following two examples illustrate variation in percentage infection which can be obtained by altering the number or distribution of samples within a plot:

In one plot 50 samples were collected at one yard intervals. *P. cinnamomi* was isolated from a total of 35% of samples. By extracting data from every alternate sample, beginning at the first or second sample respectively, the plot could have been shown to have had either 27% or 43% infected samples.

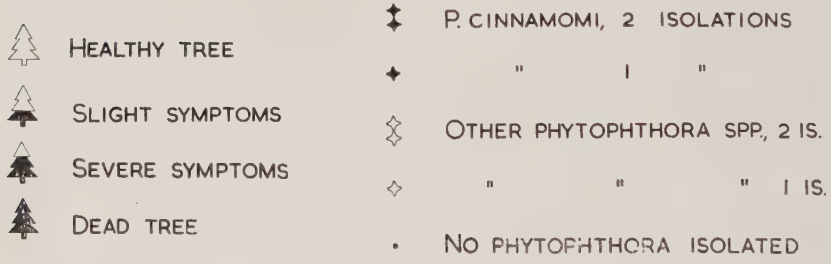
Fig. 4 shows the full data from which the double line of results for 22 May 1956 in Fig. 5 was taken. Sampling frequency was much greater than that employed in the root-zone region of survey plots or of other grids, there being two samples to each square yard over an area extending just beyond the main rootlet zone.

Taken individually the first three lines of samples would have given plot figures of 72, 88, or 80% (mean 80%) based on 25 samples per plot.

Results of Repeated Isolation from Single Plots. Fig. 5 presents successive sets of data from plot 9, adjacent to a line of 17 trees which died suddenly in early summer 1953. Successive stages of symptom development are shown, in addition to isolation data obtained on the dates indicated.

Extent of sampling varied on successive dates since the samples were not usually taken for the primary purpose of re-examining a fixed area but for other purposes e.g. grid sampling, examining distribution in depth, seasonal occurrence.

Fig. 4.—Results of close-spaced grid sampling of feeding root zone, part of severely affected row of 35-year-old *P. radiata*. Two apples per sample; ½ yd between samples, rows 1 yd apart commencing 1 yd from trunks. Percentage of infected samples in each row is shown.



Key to Figs. 4, 5, 10.

In this particular plot, when samples were collected repeatedly from a single row approximately one yard from the trees, there was a basic similarity between individual sets of results regardless of season or year. (N.B. Persistence of *Phytophthora* after death of trees will be discussed in a later section.) Collective results up to 7 February 1956 gave an almost continuous distribution of *Phytophthora* over the region most regularly sampled, although at first there appeared to be significant gaps.

When Plot 20 of Fig. 3 was sampled in January 1956, 36% of samples were positive (out of 14 samples, 13 yielded *P. cinnamomi*, 7 *P. cactorum*). Although the 40 trees in this region were outwardly healthy when first sampled (January 1956) 18 died in the following spring and summer and all except four of the remainder suffered severe abnormal defoliation and die back. While the infection figure of 36% is well within the range of values for diseased shelterbelts (Table 1), the distribution and severity of disease symptoms later the same year seemed to demand a much higher figure. Furthermore very few positive isolations were obtained from a 17-yd stretch at the south end of Plot 20, though all trees in this region subsequently died.

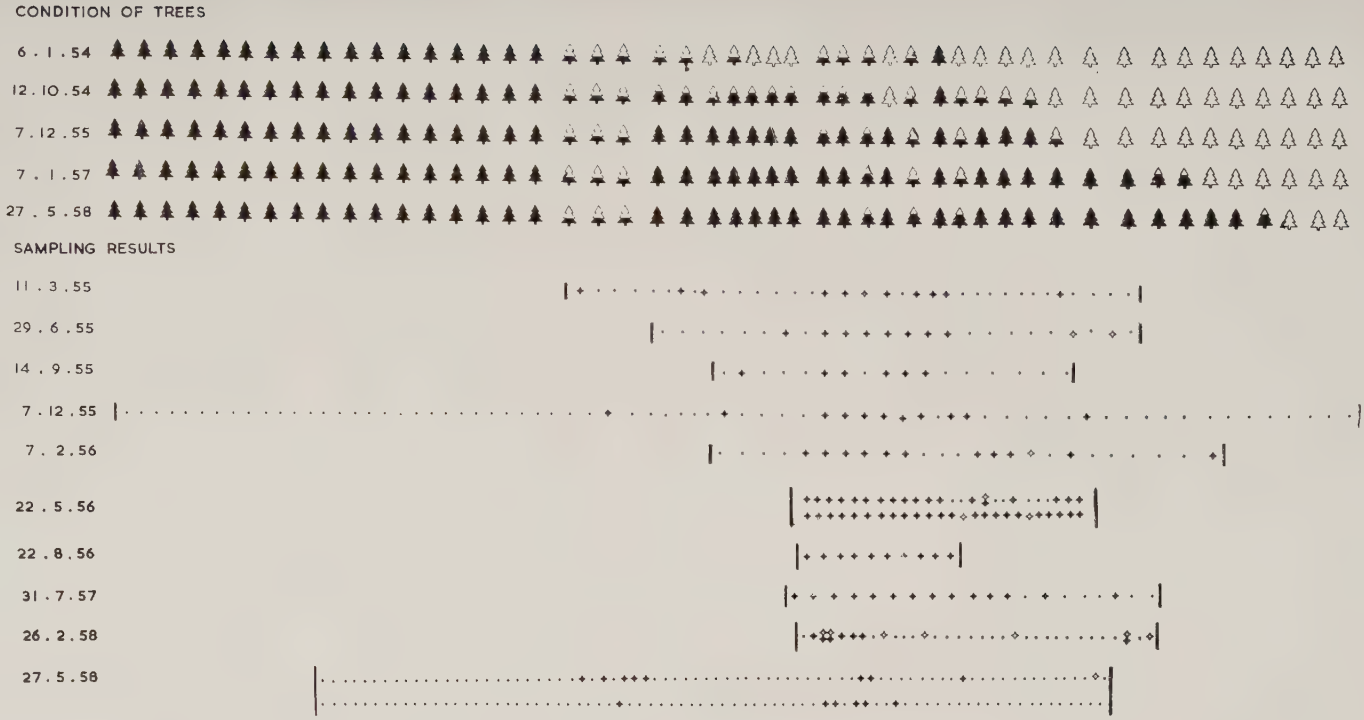


Fig. 5.—Condition of trees and results of periodical isolations from soil from Plot 9, part of a 35-year-old *P. radiata* shelterbelt. Symbols as for Fig. 4 except that stars represent presence of *Phytophthora* spp. in soil samples, not number of infected apples. Diagram is to scale, most samples being 1 yd apart and rows approximately 1 yd from trunks except for double rows which were respectively 1 and 2 yd out.

In September 1956, therefore, the region was resampled, using the three different apple-trap methods described earlier, viz. injection, burial, and storing in tins with wet soil.

There were two rows of 70 sampling sites at one-yard intervals, the rows being 2 and 3 yards from the trunks. Table 2 summarises results.

TABLE 2. RESULTS OF ISOLATIONS FROM 140 SAMPLING SITES USING THREE DIFFERENT METHODS

Method	Sites infected with *Phytophthora* spp.		No. infected sites not detected by other two methods	No. sites infected with		
	No.	%		P. *cinnamomi*	P. *cactorum*	*Phytophthora* sp.
1. Injection	60	43	27	30	33	2
2. Tins	45	32	19	13	31	2
3. Buried	29	21	13	3	22	12
Total all methods	93	66	59	36	72	15

1. Injection of apples with soaked soil
2. Standing apples on saturated soil in tins
3. Burial of apples in soil *in situ*

No. sites infected with:
P. cinnamoni + *P. cactorum*—15
P. cinnamomi + *Phytophthora* sp.—2
P. cactorum + *Phytophthora* sp.—6
All three *Phytophthora* spp.—3

The figure of 43% for the injection method is of the same order as the 36% obtained in January 1956. However, although it was the highest yield for any one treatment, it is still just under two-thirds of the total for all methods (66%). Each method detected several infected sites missed by the others and it is reasonable to suppose that further isolation attempts would have shown an even more intensive distribution of *Phytophthora* spp.

From the 34 sites in the 17 yards at the south end of the plot, although only 7, 6, and 8 positive isolations were obtained respectively by the three methods, in the aggregate there were 17 infected sites well distributed throughout both rows. The soil in this region for some reason contained much more semi-decomposed litter than most of the rest of the plot and it is possible that the difficulty of isolating *Phytophthora* spp. was in some way associated with the difference in the nature of the soil, e.g. presence of more highly competitive micro-organisms.

General Conclusions on Relationship between Sampling Data and Actual Phytophthora *Population.* Infected soil samples vary considerably

in their capacity to yield *Phytophthora* spp. when tested with apple-trap isolation techniques. The variability between soils in this respect probably accounts in part for the lack of a closer correlation between relative severity of symptoms and number of infected samples recorded in Table 1, although the correlation obtained was still significant. It would be further affected by the influence of differences in internal drainage, topography, etc.

Most of the evidence discussed in this section indicates that the actual incidence of the fungus is sometimes very much greater than that demonstrated. Although by the same arguments the recorded incidence of *Phytophthora* spp. in apparently healthy plots might be underestimated, the fact still remains that the survey data show a highly significant relationship between presence of disease symptoms in mature trees and abundant *Phytophthora* in the soil.

PERSISTENCE IN SOIL

Grid surveys showed that *Phytophthora* spp. are rarely to be found in open fields but are heavily concentrated in the rootlet region of trees. Following the assumption that they have built up in the presence of a suitable host, the question immediately arises as to whether or not the fungi rapidly disappear once the host trees are dead.

Information on persistence has been obtained from three sampling plots at Whenuapai, viz. Nos. 4, 9, and 20, of Fig. 3. Periodic isolations will continue to be made from the same plots.

Isolation results and successive stages of the disease in plot 9 are illustrated in Fig. 5. This plot includes a portion of a shelterbelt extending from a group of 17 diseased trees which died in 1953. Samples were collected from beneath these dead trees in December 1955 and all proved negative. It will be realised from earlier discussion that all negative isolations in Fig. 5 cannot be regarded as conclusive regarding absence or disappearance of *Phytophthora* from that plot. Nevertheless, it is obvious that *P. cinnamomi* either dies out or becomes harder to isolate within one to two years after death of all pine roots. It is significant that *P. cinnamomi* was isolated on the most recent occasion only from the vicinity of trees still living.

From plot 20, 14 months after death of trees, 60% of samples still yielded *Phytophthora* spp., mainly *P. cactorum*.

From part of a row of 39 trees which died in 1953 at the north end of plot 4, soil samples still yielded *P. cinnamomi* (14%) and other *Phytophthora* spp. (21%) two years after death of trees. Five years after death, *P. cinnamomi* was isolated from only one out of 85 soil samples whereas 15% of samples yielded other *Phytophthora* spp. (including *P. megasperma, P. cryptogea, P. citricola*).

These results indicate that *P. cinnamomi* is not as persistent after death of trees as are other species of *Phytophthora*.

Inoculation Experiments

Cultures of *Phytophthora* spp. isolated from soil near dying pines were used to inoculate *P. radiata* seedlings in glasshouse tests.

Experiment 1. Two-weeks-old potato dextrose agar cultures of six isolates of *P. cinnamomi* were cut into small squares and covered with tap water for three days to encourage development of sporangia. They were then macerated for 15 sec in the same water before using as inoculum. Macerated uninoculated potato dextrose agar was used for checks.

Roots of six-month-old seedlings raised in sterilised friable soil were washed carefully and dipped in one of the suspensions. They were then replanted in sterile soil, more of the same suspension being poured around them in the process.

For each fungus strain and checks four variant treatments were applied: roots were left undamaged or alternatively crushed over the lower third, and for each root condition two levels of watering were adopted, heavy (top-watered frequently) and normal (pots stood in $\frac{1}{4}$ inch of water in trays without top watering). Results are summarised in Table 3.

Of the undamaged inoculated plants 77% were affected and died or remained stunted while the corresponding checks all remained healthy; 90% of the damaged and inoculated plants likewise died or were severely affected. However, 25% of the root-damaged check plants wilted and died indicating that some losses amongst root-damaged inoculated plants may have been due to transplanting shock, particularly at the lower level of watering.

In the case of plants with roots not purposely damaged, there was an increase in infection through heavy watering.

Some plants were affected shortly after inoculation, but most became established first and then collapsed with root and collar rot.

Experiment 2. *P. radiata* seedlings grown for four months in friable sterilised soil were lifted carefully and washed free from soil. Three plants per jar were inserted through holes in lids of a series of wide-mouth jars containing aerated nutrient solution* adjusted to pH 3.5. Sides of jars were covered with dark paper.

Several weeks later, when numerous new rootlets had developed, plants were inoculated with *P. cinnamomi* following the method of Campbell and Copeland (1954). This was done by introducing a few infected wheat grains previously held for two days in soil water to encourage formation of sporangia. Half the checks and half the inoculated jars contained fresh nutrient solution, the remainder held tap water.

* Nutrient solution: KNO_3, 0.002M; $Ca(NO_3)_2$, 0.002M; NH_4NO_3, 0.002M, $MgSO_4$, 0.002M; $(NH_4)_2SO_4$, 0.003M; K_2HPO_4, 0.001M.

TABLE 3.—CONDITION OF ONE-YEAR-OLD *P. radiata* SEEDLINGS AFTER INOCULATION WITH *P. cinnamomi* MYCELIAL SUSPENSION AT AGE SIX MONTHS, WITH AND WITHOUT PRIOR CRUSHING OF PART OF ROOT SYSTEM

*Strain of *P. cinnamomi* (culture No.)	Undamaged Roots				Damaged Roots			
	Heavy Watering		Normal Watering		Heavy Watering		Normal Watering	
	Affected**	Healthy	Affected**	Healthy	Affected**	Healthy	Affected**	Healthy
Checks (sterile agar)	0	10	0	10	1	9	4	6
903	4(1)	0	2	3	3	2	3(1)	1
904	5	0	1(2)	2	3(1)	1	2(3)	0
905	5	0	3(1)	1	5	0	5	0
922	2	3	3	2	4	1	5	0
923	3(1)	1	3	2	5	0	5	0
924	5	0	4(1)	0	5	0	4	1
Total (excluding checks)	24(2) (a)	4	16(4) (b)	10	25(1) (c)	4	24(4) (d)	2

Average (a) + (b) = 77% (c) + (d) = 90%

* Isolate Nos. 903–5 from Western Springs Stadium (plot 15, Table 1)
922–4 from Whenuapai (plots 9 and 17, Table 1)

** Affected plants all died during experiment except those in brackets which remained badly stunted

In the inoculated water series, most rootlets showed orange-brown discolouration behind the tips within 10 days. All unsuberised rootlets were dead within 16 days (Fig. 6). Isolations almost invariably yielded *P. cinnamomi;* short sections of infected rootlets placed in water developed typical sporangia from cut ends overnight. Although suberised rootlets were darker than those of check plants and outwardly appeared dead, new rootlets had emerged from several by the 30th day after inoculation. These in turn were visibly infected by the 38th day. After a series of abortive attempts to produce a new rootlet system all plants were dead by 2–3 months from inoculation. A similar series of events took place with the inoculated nutrient solution series, but first signs of infection took 20 days to appear. All check plants remained healthy (Fig. 6).

Anderson (1951b) found that *P. cinnamomi* infection of pineapple roots increased with decrease in total concentration of salts, particularly of potassium. This was presumed to be because the rate of zoospore production increased rapidly with drop in salt concentration. The effect of nutrients on zoospore production probably explains the different rates of rootlet infection in the inoculation experiment using water and nutrient solution. Sporangia were present but not prolific on the inoculum and massive infection probably depended on further zoospore production after introduction of the inoculum.

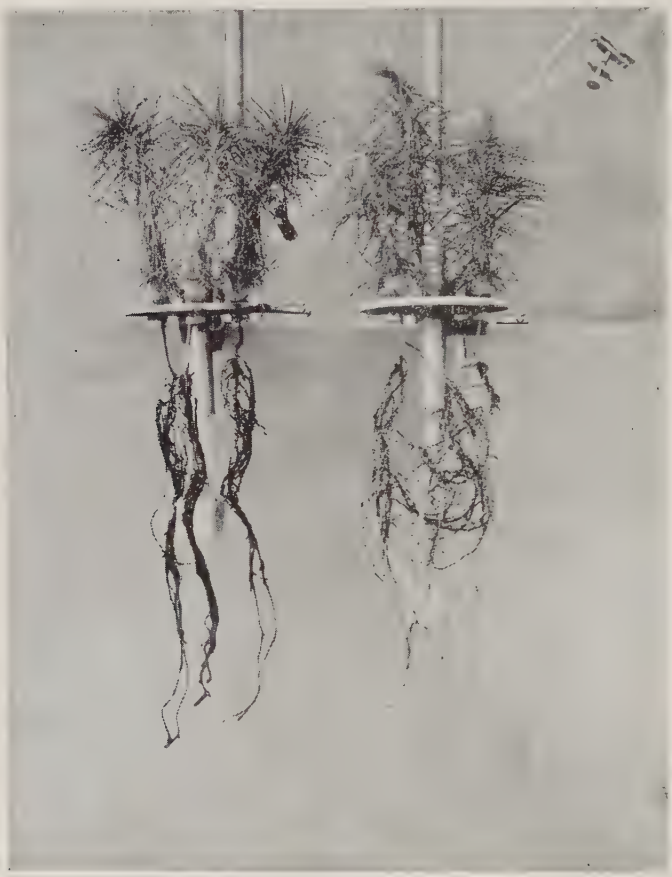


Fig. 6.—*P. radiata* seedlings from liquid culture. Left: inoculated with *P. cinnamomi*. Right: check.

Photo: S. A. Rumsey.

Experiment 3. Newly germinated *P. radiata* seedlings with radicals 1½–2 in. long were transferred to the same type of jar and grown for four weeks in aerated nutrient solution. This was then replaced by water and two inch-square pieces of soil agar culture of *P. cactorum* bearing a few sporangia were placed, out of contact with roots, in each of two jars. Three days later many rootlets were orange-brown behind the tips. By the ninth day all rootlets were infected and two plants were wilting. By the 23rd day five of the six plants were dead. *P. cactorum* was isolated from several rootlets. Fig. 7 shows the remaining plant which by this time had produced three new rootlets to replace those killed. Eight days later these in turn were dead and a third set of rootlets had grown out (Fig. 8) from initials just visible in Fig. 7. When these also became infected the plant died. All check plants remained healthy.

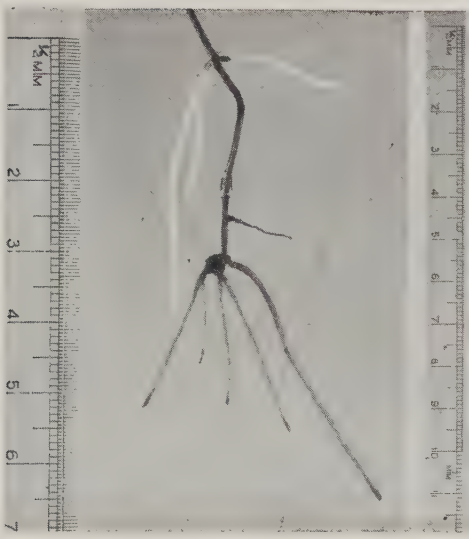


Fig. 7

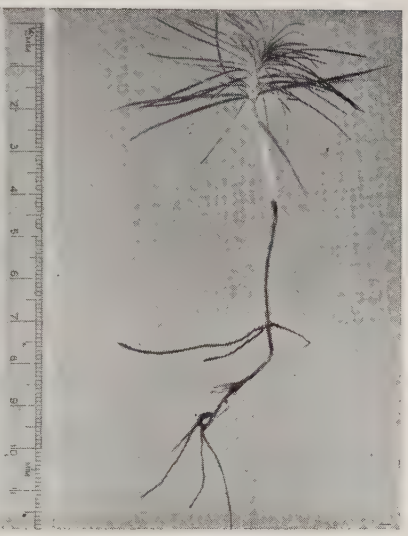


Fig. 8

Fig. 7.—Roots of *P. radiata* seedling in liquid culture inoculated with *P. cactorum* zoospores—infected rootlets replaced by three new roots.

Photo: S. A. Rumsey.

Fig. 8.—Same seedling as Fig. 7, eight days later.

Photo: S. A. Rumsey.

Experiment 4. Similar results were obtained with further inoculations using *P. cinnamomi* on four- and six-month-old *P. radiata* seedlings grown in aerated nutrient solution.

Experiment 5. Twelve six-month-old *P. radiata* seedlings raised in sterilised soil were transplanted carefully to 4-inch pots of non-sterilised soil from a bulk sample taken from below badly diseased trees (centre of plot 9; see Fig. 5). Part of the same bulk sample was steam sterilised and used to plant another 12 seedlings. Pots were kept in trays with $\frac{1}{4}$–$\frac{1}{2}$ inch of water.

After seven months, when three plants in the former series had died and obvious differences in vigour separated the two series, all plants were lifted and root systems examined. Plants in sterilised soil were pot-bound, with healthy root systems. Roots of plants in non-sterilised soil were sparse and either dead, or lacking in coralloid rootlets. *P. cinnamomi* was isolated from several infected rootlets.

Similar results were obtained in another experiment with the same soil, using 18-month-old plants, full details of which are given in a later section dealing with soil moisture and infection.

AGE AND SUSCEPTIBILITY

Natural infection of *P. radiata* with *P. cinnamomi* occurs frequently in the form of damping-off and death of nursery stock up to three years of

age. In these instances there is infection of main roots and lower stems. On two occasions *P. cinnamomi* was isolated from root rot of badly reddened, dying five-year-old trees. Judging by field behaviour in localities where mature trees have been badly affected, shelterbelt trees appear to be resistant from the age of five or six years to the age of twenty or more. Most severe losses have occurred in trees 30 years of age or older. Increased susceptibility appears to coincide roughly with the change from a conical growth form to the mature phase with large spreading branches in the upper crown.

Two examples will be described which illustrate the difference in susceptibility between the two age classes:

1. Property P. Richards, Redoubt Rd; plot 14; Brookby clay loam, hill phase, fairly well drained, slight to moderate slope. Samples were taken from soil below an apparently healthy 15-year-old hedgerow at right angles to a badly diseased row of trees 40–45 years of age. There was essentially the same amount of soil infection in each case, viz, 36% and 30% total *Phytophthora* spp. respectively.

2. Property Mrs. Green, Dairy Flat; plot 2; Wharekohe silt loam, one of the poorest-drained soils of the North Auckland "gumland" complex.

Fig. 9 is a view of the north end of the small plantation shown in diagrammatic form in Fig. 10.

Fig. 9.—View of north end of Plot 2 (see also Fig. 10) showing resistant 12-year-old trees on left and badly affected 37-year-old trees on right.

Photo: J. W. Endt.

On the east side on a low terrace, is a narrow belt 7 yd wide of closely planted *P. radiata* (A in Fig. 10) 12 years old at time of sampling. On the west side, just below road level (Fig. 10 B), is a line of young trees of the same age as the first, separated by a gap of seven yards from a row of mature 37-year-old trees (Fig. 10 C). There is a steep fall to a stream on the west and a gentle downward slope from south to north over the planted area.

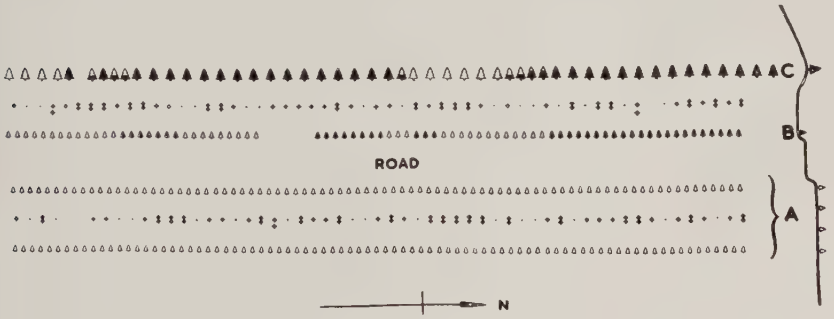


Fig. 10.—Diagrammatic representation of Plot 2. A—7-yd-wide belt of closely spaced outwardly healthy 12-year-old trees; B—line of 12-year-old trees in which deaths corresponded with ponding areas; C—line of 37-year-old trees, mostly dead. Cross-section profile of plot shown at north end. Symbols as for Fig. 4. Spacing of tree symbols is schematic with exception of living diseased trees.

Most of the older trees had died prior to sampling in January 1956. Many of the younger trees (B) on the west side of the roadway were dead but all those on the east (A) were outwardly healthy. On each side of the road 57 soil samples were collected at two yard intervals up the centre line between the trees. Fig. 10 shows results of isolations and the distribution of dead and diseased trees.

The *Phytophthora* population on each side was well distributed and similar in amount: east side 68% (*P. cinnamomi* 65%), west side 72% (*P. cinnamomi* 61%).

During the winter and spring of 1956, one of the wettest seasons on record, it was seen that waterlogging was severe on all parts of the plot. In addition, impeded surface drainage caused ponding in low areas between the road and the mature trees. These corresponded exactly to the regions in which young trees had died. Following this exceptionally wet winter, epidemic mortality occurred in this and other districts yet the young trees on the east side of the road suffered no more than a somewhat heavier than usual needle fall.

The general conclusions to be drawn from this plot are:

(a) Under comparable drainage conditions on a soil which waterlogs very badly, young trees 12 years of age showed a high degree of resistance to *Phytophthora* attack inasmuch as they showed

relatively slight or no outward symptoms, while 37-year-old trees had a high death rate.

(b) Where naturally poor drainage was aggravated by surface ponding, however, then apparent resistance of the young trees broke down and they died.

Relationship Between Soil Moisture and Infection

Phytophthora spp. need high soil moisture for dispersal of zoospores. Serious rootlet infection therefore can only occur when wet soil conditions exist for a sufficiently long period. The widespread occurrence of severe symptoms in two abnormally wet seasons has already been mentioned and also the susceptibility of otherwise resistant twelve-year-old trees under the combined influence of a wet situation and exceptionally wet seasons.

Influence of Seasonal Rainfall. Table 4 gives average rainfall for each month and deviation from average of the rainfall for each month of the eleven to fifteen years for which such data are available for Kaitaia, Whangarei, and Whenuapai, representing the northern, central, and southern portions of the North Auckland Peninsula.

Summer soil moistures in most parts of the country are too low for *Phytophthora* attack. It is well recognised that the clay soils characteristic of the North Auckland Peninsula shrink during normal summer drying to form massive soil columns which do not re-wet readily. Much of the autumn rain is lost as run-off and in most years the main body of soil remains relatively dry until June or July.

Since distress symptoms in trees normally develop early in spring, it is obvious that most rootlet infection is confined to the winter or autumn and winter months. Damage could be expected to be most severe following excessive autumn rainfall as roots will then be exposed to *Phytophthora* attack for a longer period than usual. Moreover autumn soil temperatures are more favourable for fungus activity than winter temperatures*.

On grouping rainfall data into deviations from average for autumn (April–June) and winter (July–August) (Fig. 11), it was seen that, in fact, epidemics occurred only in years and districts in which autumn rainfall was considerably above average. Winter rainfall in these cases was normal or above, ensuring that conditions would favour a continuance of attack on regenerating rootlets.

The late Mr. G. H. Smith of Te Hana, in a letter to Mr. Sutherland, Soil Bureau, stated that pine losses in the Wellsford district in 1924, 1937, and 1946 all occurred in spring after a wet autumn and winter which had been preceded by an abnormally dry summer. This statement was borne out by rainfall data collected by him at a local school.

* Average soil temperatures at Plant Diseases Division, Auckland taken from daily readings at 9 a.m. at 4 and 8 inches depth April, 15°–16°C; May, 12.5°–13.5°C; June, 10°–11.5°C; July, 8.5°–9.5°C; August, 9.5°–10°C.

TABLE 4. RAINFALL DATA FOR NORTH AUCKLAND PENINSULA

Met. Sta.	Mth.	Av. for Mth.	Deviation from Average (in.)														
			1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
A. KAITAIA	Jan.	3.48	−2.36	+5.02	−2.20	−1.86	−0.68	−0.40	−2.40	0.00	−1.07	−1.39	−3.09	−1.20	+6.58	−2.85	−0.52
	Feb.	3.65	+0.74	+0.09	−3.24	−2.86	−2.23	+1.95	−3.14	+4.73	+2.92	−0.70	−1.66	−1.94	+0.32	−0.33	+10.14
	Mar.	3.14	+2.30	−1.21	−1.25	−1.48	−0.04	+2.09	−2.86	−2.37	−1.53	−1.70	+3.15	+1.03	−1.82	+1.78	−2.36
	Apr.	5.02	+1.22	+0.04	+4.56	+2.73	+0.25	+0.30	+1.92	+0.77	−2.71	−1.57	−0.31	−2.63	+3.62	−1.88	−3.60
	May	6.06	−1.50	+1.64	+0.37	−3.55	−0.33	−0.39	+1.48	—	−2.20	+1.77	+2.21	−1.91	+6.35	−1.07	−2.00
	June	6.57	−1.98	−2.74	+3.39	−0.60	−2.14	+0.02	−0.18	+0.45	−0.97	−2.76	−0.42	+1.55	+6.68	−3.61	−3.50
	July	6.35	−2.93	−1.21	+1.49	+2.50	+0.99	−2.84	−4.11	+0.01	−4.38	−1.43	−0.12	−1.36	+0.97	−2.61	+0.97
	Aug.	5.70	−0.26	+0.44	+0.64	−1.70	−0.08	−1.11	−3.03	+1.65	+0.70	+8.73	+1.34	−2.57	+4.44	+5.81	−2.95
	Sept.	5.15	−2.86	+2.79	+0.42	−0.17	−2.89	−1.75	−2.98	−2.57	−3.15	−3.55	−0.24	+2.36	−0.08	−0.55	+1.24
	Oct.	4.74	+1.11	−1.21	−0.31	−1.12	+0.24	−1.78	+0.61	−2.06	−0.61	+0.12	−1.17	+4.36	+0.94	−0.71	—
	Nov.	3.60	−2.82	−2.92	−0.30	+1.08	—	+1.12	+1.27	+1.58	+4.32	+1.37	−1.40	+1.79	+1.35	−1.59	—
	Dec.	3.32	−0.38	−2.16	−1.12	+2.71	+0.05	−0.59	−1.00	+0.01	+0.37	−2.62	−0.05	+0.64	+1.83	−0.78	—
B. WHANGAREI	Jan.	4.65	—	—	—	—	−1.77	+0.40	−4.31	+0.44	−2.65	−2.03	−3.89	−3.98	+3.12	−4.21	−2.60
	Feb.	4.24					−1.48	−1.03	−3.59	+5.72	+17.47	−2.01	−0.97	−1.70	+2.44	+1.36	+8.54
	Mar.	5.05					−0.96	−1.74	−3.65	−1.35	−3.54	−3.34	+8.72	+12.51	−1.97	+7.19	−2.12
	Apr.	5.83					−0.34	−1.42	+5.64	+2.18	−4.06	+1.75	−1.24	−3.32	+13.91	−2.56	−4.97
	May	7.46					−1.71	+1.78	+2.75	−2.17	−3.70	+0.73	+4.97	+1.24	+13.68	−2.95	−1.71
	June	7.13					−2.12	−2.18	−2.16	+3.58	−0.77	−1.67	−3.21	+4.07	+3.61	−3.41	−4.60
	July	8.06					+1.36	−5.28	−6.63	−1.68	−5.92	+1.14	+0.80	−2.96	+3.67	−4.20	+9.24
	Aug.	6.81					+3.71	+0.02	+0.91	+4.93	+5.57	+8.27	+4.69	−3.50	+6.12	+4.54	−4.24
	Sept.	5.45					+1.48	−2.55	+3.22	−3.62	−1.74	−1.51	+2.42	+0.83	+1.08	−1.33	+2.72
	Oct.	4.98					−1.07	−3.14	+2.00	−1.81	−0.52	−0.13	−2.24	+10.36	+2.93	−1.15	--
	Nov.	4.04					+1.28	+3.79	+1.99	+0.54	+3.60	−0.73	−1.22	+2.50	+1.17	−2.12	—
	Dec.	3.63					−2.37	+0.62	+1.19	−0.87	+2.24	−0.93	−0.19	+7.21	−0.92	−1.46	—
C. WHENUAPAI	Jan.	3.59	—	—	−2.41	+0.11	−0.23	−0.45	−2.96	−0.65	−2.26	+0.22	−3.25	—	+2.07	−3.29	−2.07
	Feb.	4.36			−4.17	−3.08	−3.32	−1.02	−3.11	−0.30	+1.47	−2.18	−2.28	−2.17	−0.32	−2.85	+5.97
	Mar.	3.26			+0.82	+3.61	+0.58	−0.32	−1.62	−1.57	−2.31	−1.13	+6.30	+2.02	−2.22	+1.27	−0.71
	Apr.	4.84			+0.38	+3.82	+0.48	+2.17	+2.35	+3.86	−2.56	+1.45	+0.51	−2.41	+6.85	−2.46	−3.36
	May	5.44			+1.40	−2.26	+3.54	+1.82	−2.43	−1.11	−1.52	+2.93	+7.13	−0.56	+1.24	+0.33	+2.84
	June	6.05			−2.63	+3.50	−0.71	−0.04	+2.99	−1.62	+1.06	+2.42	−1.84	+1.93	+4.76	−1.65	−4.13
	July	6.60			+1.17	+1.92	+3.78	−1.53	−4.36	−0.12	−2.33	−0.07	−1.67	−2.82	+0.33	−3.65	+1.29
	Aug.	4.83			+3.41	−0.65	−0.84	−3.38	−3.12	+1.43	+2.15	+4.04	+1.38	−2.02	+2.75	+0.06	−1.19
	Sept.	4.19			+0.97	+0.49	−0.37	−2.38	−2.12	−3.50	−0.76	−2.01	+0.52	−0.24	+1.54	−1.70	−0.53
	Oct.	4.42			+0.67	−1.02	+5.17	−2.06	+2.07	+1.32	−1.13	−1.26	−2.38	+1.95	+2.71	+1.56	—
	Nov.	3.76			+2.87	−0.91	+1.52	+0.81	+4.44	+1.31	+4.02	−1.87	−1.94	−0.04	−0.48	−1.24	—
	Dec.	3.30			+0.09	−0.28	−0.70	+0.50	−0.35	−1.03	+0.18	−0.87	+1.22	+0.36	+1.87	−0.69	—

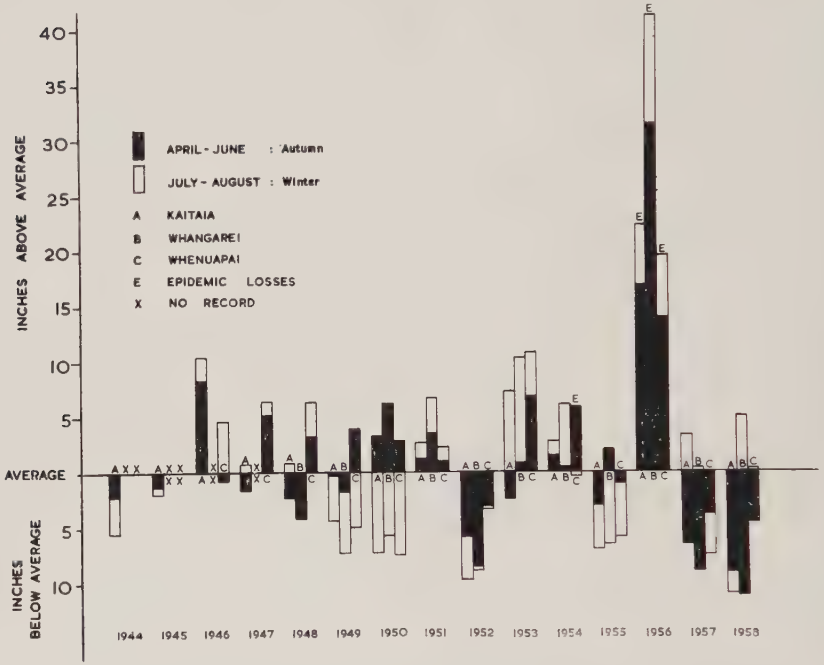


Fig. 11.—Yearly deviation from average of autumn and winter rainfall in North Auckland Peninsula.

A drought preceding early and heavy autumn rains may well be important in some seasons. Mr. C. F. Sutherland (pers. comm., 1958) reported that excessive dryness during droughts causes fragmentation of the massive soil columns induced by normal summer shrinkage in strongly leached North Auckland clays and that this fragmentation actually assists re-wetting in autumn. Droughts preceded the epidemics at Whenuapai in 1953, 1954, and 1956. On the other hand, the summer preceding the 1956 epidemic was abnormally wet at Kaitaia and Whangarei. The 1956 rainfall was the highest on record throughout the North Auckland Peninsula and it can be presumed that drought fracturing was not necessary for early saturation of the soil. A drought preceded a wet autumn and winter at Kaitaia in 1946 but no information is available as to whether trees died in that district. There were considerable losses in that year, however, in the Wellsford district where the late Mr. G. H. Smith recorded a very dry summer followed by a consistently wet autumn and winter. Summer drought alone, not followed by excessive autumn and winter rainfall, did not lead to epidemics (1946 7, A 1947–8 ABC, 1954–5 AB, Fig. 11).

With regard to the occasions on which there was excessive autumn rainfall but no epidemic, Table 4 and Fig. 11 show that there were such factors as no prior drought (1947 C, 1951 B), autumn rainfall not consistently heavy in all three months (1947 C, 1948 C, 1951 B) or an abnormally dry winter (1949 C, 1950 ABC).

To summarise, it would seem that the critical weather conditions for epidemic pine losses, in order of importance, are firstly an autumn in which the monthly rainfall is consistently well above normal, secondly an average or wet winter, and thirdly prior summer conditions which are conducive to rapid re-wetting of soil in the autumn. The latter may be either drought or abnormally high rainfall.

Influence of Soil Moisture. An experiment with naturally infected soil gave information on the reaction of *P. radiata* root systems to *P. cinnamomi* under a variety of soil moisture conditions. Forty pot-bound 18-month-old plants in 4-inch pots were selected for uniformity of tops

Fig. 12.—Typical plants from experiment with naturally infected soil. Left: pot-bound plant in steam-sterilised soil. Right: plant in non-sterilised soil with most roots rotted.

Photo: J. W. Endt.

and roots. They were carefully transferred to 6-inch pots, 20 into steam-sterilised and 20 into non-sterilised soil from an infected bulk sample from Plot 9. Pots were kept in trays with half-an-inch of water for seven months. There were no obvious outward differences in vigour or health between the two groups. However, the root systems differed markedly. All 20 in sterilised soil had again become pot-bound with prolific coralloid rootlets, healthy at all levels. None of the plants in non-sterilised soil were pot-bound; five plants were somewhat less affected than the others, but in all cases roots penetrating the lower, wetter layers of soil had rotted and soil fell away (Fig. 12). In the upper soil, roots were mainly healthy but much less prolific than in the sterilised soil and bore very few coralloid rootlets.

Without further disturbance to roots, plants were replaced in their pots and the experiment reorganised. Three treatments were applied to twelve plants from each of the sterilised and non-sterilised groups, selected for uniformity of root systems.

(1) Four pots removed from trays, no further watering for five months.

(2) Four pots left in trays, $\frac{1}{4}$–$\frac{1}{2}$ inch of water maintained.

(3) Four pots kept submerged to soil level for five months, water not changed.

Results

(1) This part of the experiment was set up early in February with glass-house temperatures frequently reaching 90-100°F. until the end of April. Plants of both unwatered groups were unaffected for three months but were wilting badly by the end of the fourth month. After five months they were soaked and replaced in trays of water. In the non-sterilised group, three plants failed to recover while all shoot apices died in the fourth, being replaced by new laterals late the following spring. In the sterilised soil group one plant died, all shoot apices died on another, while the remaining two eventually made normal but belated spring growth as new root growth increased. Older needless developed severe tip die-back; many were cast.

(2) At the end of the fifth month the tray-watered groups were both outwardly healthy although plants in sterilised soil were more vigorous. Roots of the latter series were still healthy. Roots in non-sterilised soil had increased considerably in the upper layers, since the previous lifting and replacing had broken the capillary connection between top and bottom layers in the pot. Where roots had eventually begun to penetrate the wetter lower layers again almost all were rotted. Several orange-brown newly infected roots were removed and cut into small segments. Many of these when placed in water overnight developed sporangia typical of *P. cinnamomi* from the cut ends; others yielded *P. cinnamomi* after plating on soil agar.

(3) Roots in non-sterilised soil died within a month of submergence. Those in sterilised soil deteriorated slowly: most were healthy after a month; after three months most still had white steles although cortical tissues were black; after five months all appeared dead. Normal tray watering was then resumed as with the drought series. Normal but late spring growth occurred in both groups following root regeneration.

Subsequent behaviour of plants: After a further 14 months growth under uniform tray-watering conditions, the root systems of all three groups were again examined and found to have reverted to essentially the same condition as at the end of the first part of the experiment, i.e. pot-bound and healthy in sterilised soil, living roots only in upper halves of pots of non-sterilised soil.

At the end of 14 months, groups differed markedly in shoot growth. Measurements (in centimetres) were made of height to the top of the crown bud and of stem diameter 5 cm above soil level. For comparative purposes, total growth was expressed as the product of height and the square of the diameter. Results are presented in Table 5.

The results showed an over-all difference between sterilised and non-sterilised soil that was significant at around the 2% level.

TABLE 5.—EFFECT OF FIVE MONTHS' DROUGHT OR FLOODING ON SUBSEQUENT GROWTH OF TWO-YEAR-OLD *P. radiata* IN NON-STERILISED AND STERILISED NATURALLY INFECTED SOIL

Growth is expressed as the product of height and diameter^2 ($H D^2$) (measurements in cm) 14 month after resumption of "normal" watering

Watering Regime	Soil Condition			
	Non-sterilised		Sterilised	
	$H D^2$	Av.	$H D^2$	Av.
1. Drought	133	133	109, 179, 123	137
2. "Normal"	164, 176, 384, 369	273	412, 502, 410, 387	428
3. Flooded	96, 247, 203	182	252, 213, 462, 227	288

Overall means for:				
Non-sterilised soil		176	Drought	108
Sterilised soil		287	Normal	351
			Flooded	235
L.S.D.	5%	88	5%	111
	1%	122	1%	154

In addition to death of four plants through drought (three in infected soil) there was a highly significant difference between growth following drought and that following normal watering. The over-all effect of drought was worse than that of flooding, and growth was less after flooding than in plants tray-watered throughout, the differences in each case being significant at the 5% level.

Interaction between soil condition and watering regime was negligible. Although at first one might have expected an interaction between flooding and infection, having regard to the known dependence of *Phytophthora* spp. on free soil moisture for attack, the conditions of the experiment did not allow detection of such an effect in terms of tree growth: although roots were killed 2–4 months earlier in non-sterilised soil, drought and flooding were so prolonged that virtually all feeding roots were killed in both sterilised and non-sterilised soil, leaving no room for differences. Regeneration from larger roots and subsequent growth of aerial parts of plants occurred (in both sets of soil) only after uniform (tray) watering conditions were restored.

While the severity of the drought and flooding conditions thus defeated the object of this part of the experiment as regards growth measurement, the aggravating effects of free soil moisture on the disease were still to be seen from

(1) A greater number of deaths in non-sterilised soil than sterilised soil (four to one).

(2) Increased root rot in the wet bottom soil of tray-watered infected pots.

(3) Much more rapid death of roots as a result of flooding in infected than in sterilised soil, though death of feeding roots was eventually complete in both.

Other conclusions from the trial are:

(4) Outwardly similar plants may differ drastically in root health. This is due to a considerable lag between root death and symptom expression.

(5) *P. radiata* in the summer phase of growth has a high degree of tolerance to drought and flooding.

(6) *P. radiata* has a strong capacity for rootlet regeneration following removal of adverse conditions.

The influence of soil drainage on the disease in the field will be discussed in greater detail in the next paper of this series.

Phytophthora Spp. and Conifers Other than *P. radiata*

As stated in the introduction, *P. cinnamomi* was isolated from roots of dying *C. lawsoniana* in two Waikato shelterbelts in 1952. The death of this species in wet situations is not infrequent. The disease is commonly referred to as "wet feet", implying a physiological condition, primarily, rather than a pathological condition. Field observations indicate that wet conditions by themselves may result in severe stunting and unthriftiness but seldom in death. Loss of trees occurs when *Phytophthora* infection is present and this involves vigorous and relatively vigorous trees as well as stunted ones (Fig. 13).

Fig. 13.—*Phytophthora* infection of *C. lawsoniana* shelterbelts near Cambridge. Trees missing from flooded area in centre, stunted and dead at right, and suddenly dead after previously making normal growth at left.

TABLE 6. *Phytophthora* spp. ISOLATED FROM SOIL BELOW TREES OF OTHER CONIFERS WITH SYMPTOMS RESEMBLING THOSE OF *P. radiata*

Location	Soil	Species	Disease Severity	% Soil Samples Infected with			Total % Infected Samples
				P. cinnamomi	*P. cactorum*	Other *Phytophthora* spp.	
1. Flat Bush	72b	*P. muricata*	xxx	22	39	39	72
2. Flat Bush	72b	*P. muricata*	xxx	1	8	32	36
3. Sth. Motorway	34b	*C. macrocarpa*	xxx	2	14	30	44
4. Ardmore	107d	*C. macrocarpa*	xxx	0	10	32	36
5. Ardmore	107d	*C. lawsoniana*	xxx	46	0	2	46
6. Rosebank Rd.	73	*C. lawsoniana*	xxx	30	32	4	60
7. Rosebank Rd.	73	*C. lawsoniana*	xxx	4	20	2	20

Key to soil types:

34b Manurewa silt loam; from pumiceous sandstone; drainage poor to fair.
72b Flat Bush silt loam; water sorted volcanic ash; drainage poor to fair.
73 Waitemata complex; water sorted ash, peat, sandstone; soil drainage often poor.
107d Ardmore peaty loam; peat alluvium from volcanic ash.

During the survey of the North Auckland Peninsula (see p. 809) 47.7% (412 and 863) of C. *macrocarpa* and 65.4% (89 out of 136) of *C. lawsoniana* shelterbelts or clumps observed were seen to be severely affected.

Using the standard apple-injection method, isolations were made from soil below dead or dying *P. muricata, C. macrocarpa* and *C. lawsoniana* growing near Auckland. Table 6 summarises results of this survey.

It will be seen that *Phytophthora* populations are comparable with those from beneath infected *P. radiata.* "Other *Phytophthora* spp." refers to *P. cryptogea* in all except No. 3 where 14% of samples yielded a *Phytophthora* sp. as yet undetermined.

In addition to the above, *P. cinnamomi* has been isolated from roots of 25-year-old and one-year-old kauri (*Agathis australis* Salisb.), 14-year-old Irish yews (*Taxus baccata* var. *fastigiata* Loud.) and seedling Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britt.).

Of practical interest here was the isolation of *P. cinnamomi* from root- and collar-rot lesions of blue lupin (*Lupinus angustifolius* L.) grown as a cover crop on nursery beds with a history of kauri seedling mortality. *P. cinnamomi* and *P. cryptogea* were isolated from dying kauri seedlings in adjacent beds.

Although no isolations were made from soil or roots, *P. pinaster* and occasionally *Cupressus lusitanica* var. *benthami* Carr. were seen to be typically affected during the survey of North Auckland.

Phytophthora Spp. from Forest Soils

The situation in forests is more complex than in shelterbelts. Many factors other than fungus attack undoubtedly contribute to death or loss of vigour of forest trees e.g. competition, nutritional deficiency, attack by insects.

Phytophthora spp. have been isolated in considerable quantity from several North Island forest areas. The extent to which root infection by *Phytophthora* spp. might be an additional or contributory factor in loss of forest trees will be discussed in a later paper. In the light of results from shelterbelts, however, it is obvious that where *Phytophthora* spp. are present they must be regarded as pathogens, contributing to the disease complex of the forest.

Discussion and Conclusions

The difficulty of isolation of *Phytophthora* spp. from most types of infected tissues is well known. Early experience showed that isolation from infected roots of *P. radiata* is no exception. On the other hand, isolation from soil by the apple-trap technique was successful within certain limits. Isolations from soil rather than from host tissues merely provide circumstantial evidence of an association between pathogenic fungi and diseased host plants. Such evidence is important in the present case because pathogenicity of *Phytophthora* spp. to mature trees

has not been proved by inoculation. Normally, satisfying Koch's postulates with young plants is sufficient. While pathogenicity has been proved on young plants of *P. radiata,* mature trees are separated from pot plants or nursery trees by an apparently resistant immature phase of many years duration. It has not been found possible to obtain a sufficient number of suitable mature trees for deliberate inoculation.

The results of soil isolations from grid and linear surveys on a large number of affected properties showed that there was a highly significant correlation between presence of *Phytophthora* spp. and death of mature *P. radiata* in shelterbelts. *Phytophthora* infection under wet conditions would seem to be the main limiting factor in health and vigour of pine shelterbelts on farms; competition is slight, soils benefit from top-dressing and stock excreta, and tree growth has usually been excellent, even on originally poor soil types, prior to defoliation and death. In forests, on the other hand, the situation is more complex. Competition, poor nutrition, adverse soil physical factors, attack by *Sirex* etc., may all affect the general health and vigour of New Zealand *P. radiata* stands (Weston 1956; Sutherland pers. comm., 1957; Atkinson 1958; Rawlings 1955). Under these circumstances rather more precise information about *Phytophthora* distribution is required in order to appreciate more correctly the relative role of *Phytophthora* spp. under forest conditions. For this reason considerable emphasis has been placed in this paper on attempts to estimate the reliability and limitations of the isolating techniques used, before proceeding to discuss the results of forest investigations in later papers. Among the causes of failure of the isolating techniques used are the difficulty of breaking dormancy of *Phytophthora* oospores, microbiological antagonism, and swamping of *Phytophthora* spp. by faster-growing saprophytes also capable of invading apple tissue. The importance of these factors varied greatly between and within plots.

Following the 1953 epidemic of shelterbelt deaths, a widely held theory was that stock congregating for shelter under branches had either overcompacted the soil or caused death of roots through an excess of nitrogen. A secondary influence by stock on disease development cannot be overlooked, but the fact remains that numerous and often extensive examples of pine deaths occurred in the absence of stock, e.g. double-fenced shelterbelts, trees on golf courses, parks, and residential properties, etc. Furthermore where farm trees were unprotected it was not always the favourite stock "camping" areas that were affected; in cases where it was, however, it is quite possible that increased nitrogen would increase susceptibility or that trampling would reduce soil permeability and lead to waterlogging favourable to *Phytophthora* spp.

The following interpretation of the etiology of the disease on *P. radiata* would appear to meet observed facts:

Seedlings are susceptible to damping-off by *Phytophthora* spp. and main root and collar infection can continue, under sufficiently wet conditions, until plants are three or four years old. Except where actual flooding occurs, trees then seem to be resistant for several years in the

phase when trees are still conical in form, and growth is dominated by increase in height. Towards the end of this period and more particularly when trees are entering the spreading-upper-crown phase of growth—usually after 20–30 years of age—they become much more susceptible, and spectacular outbreaks of disease symptoms occur. It is unlikely that in most cases these sudden deaths represent a new invasion of a pathogen. It is more likely that trees have tolerated *Phytophthora* in the soil for many years, the fungi having been native to sites or having been introduced with trees from nurseries. In this connection it is not uncommon for commercial nurseries to be heavily contaminated with the same *Phytophthora* spp. as are encountered in pine hedgerows. Unlike the major root and crown rots caused by the same species on many other hosts, root symptoms on *P. radiata*, as with *P. echinata* (Campbell and Copeland 1954, and others), are largely confined to the fine unsuberised absorbing rootlets. In this respect the attack can be likened to a "damping-off" effect extending into the adult life of the trees. Adventitious rootlets replaced those killed, in the manner illustrated by some of the inoculation experiments. In the vigorous intermediate growth phase and in most seasons in the case of mature trees, rootlet regeneration is probably more than sufficient to replace rootlets killed by infection during the wet winter months. The capacity for rootlet regeneration may diminish as plants get older. If abnormally wet conditions begin early in autumn and continue on into the spring, the rootlet balance is not restored sufficiently and trees suffer from drought even though there is otherwise adequate soil moisture. It is likely that susceptibility of *P. radiata* to drought is greatest in spring. At this time the main bulk of new shoot and needle growth is occurring, and transpiration demand is increasing. Death would be a result of drought caused by extensive death of rootlets at a critical period of growth.

Sometimes trees are affected but not seriously enough to die. They suffer severe defoliation and, while some gradually deteriorate further and others improve, many remain in a sparsely foliated condition for five years or more. New needles are short and tufted on ends of new twigs of very limited growth. The apparent resistance of such trees may be due to a restored balance, at a lower level than previously, between transpiring surface and the badly damaged rootlet system. Two groups of trees in such a condition are still alive at the left and centre of the stretch of trees shown in Fig. 5 although mortality has spread well beyond them in successive seasons.

One of the main characteristics of the disease is the spectacularly rapid death of previously vigorous healthy-looking trees. It is tempting to suspect the action of a toxin but the explanation may again be found in the relationship between transpiring area and effective root surface. For example, shelterbelt trees on fertile farmland have long needles, good needle retention, and crowns extending to ground level or to grazing height. They can be expected to suffer more drastically, if severe rootlet mortality occurs at the critical time in spring, than trees with lower transpiration demand, e.g. partially defoliated trees, trees on poor sites, or forest trees with crowns restricted to the upper third or so of their height.

It follows that differences in transpiration demand could explain why *P. radiata* in New Zealand shelterbelts usually succumbs more rapidly than *P. echinata* in forests of the U.S.A. Where *P. radiata* trees do not die immediately but are severely defoliated and have short tufted needles, the symptoms are entirely comparable with those of *P. echinata* suffering from littleleaf disease. From personal observations in southeastern U.S.A. it is considered that the New Zealand disease is basically the same as the littleleaf disease of the southeastern U.S.A.

Campbell and Copeland (1954) found a strong correlation between impeded soil drainage and little-leaf disease. Zoospore production and rootlet infection depend on free soil moisture and Zak (1954) has further suggested that abundant moisture in heavy soils produces anaerobic conditions which aggravate root injury. Campbell and Copeland also indicate that low fertility may influence the development of little-leaf symptoms. Low fertility seldom influences the situation in New Zealand farm shelterbelts which normally benefit from fertiliser applications and from animal excreta. While the disease in New Zealand is certainly worst on heavy soils with impeded internal drainage, it is also present on well drained soils. Its occurrence in epidemic form in certain years on all soils suggests that exceptionally heavy seasonal rainfall is more important than poor drainage alone as a major factor in disease development.

Prolonged or exceptionally heavy rain, in addition to providing free soil moisture for zoospore infection, might also leach soluble salts from the surface soil where most rootlets are present. As with *P. cinnamomi* infection of pineapple (Anderson 1951a), this might lead to increased infection of roots through encouragement of more rapid zoospore formation.

In the matter of control, it might seem logical to counter infection by manuring to stimulate new root growth, but in the light of above comments on the subject of transpiration demand it must be expected that the inevitable increase in top growth might render trees more likely to die in the occasional abnormally wet season. Improving drainage may reduce the risk of mortality but in heavy soils internal drainage may still be too slow for this to be effective. Furthermore continual rainfall may nullify the benefit from improved or naturally good drainage. This was particularly noticeable during the survey of Northland after the 1956 epidemic when, following an abnormally wet season, several cases of severe mortality were seen on well drained soil types and on fairly steep slopes.

Since soil treatment on a large scale with fungicides would be expensive and not necessarily effective because of the difficulty of obtaining penetration to an effective depth, the most practical answer to the disease lies in the use of resistant species for farm shelter. Unfortunately, the susceptible *P. radiata, C. macrocarpa,* and *C. lawsoniana,* have tended to become the dominant shelter species in New Zealand. *C. lusitanica* var. *benthami* raised from seed exhibits too much variability in both morphology and resistance to be a satisfactory replacement,

although it is often regarded as such. Zak (1955) in the case of littleleaf disease found that there was inheritable resistance of *P. echinata* to *P. cinnamomi*. In the case of *P. radiata* a breeding programme would involve not only resistance to *P. cinnamomi* but also to several other species of *Phytophthora*. This would of necessity be a very long-term project and may have inherent limitations (Boyce 1957). In the meantime there is an urgent need for surveys of alternative shelter species in badly affected districts, along with experimental plantings of apparently resistant coniferous and broadleaf trees in a wide range of climatic and soil types.

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THE ASSOCIATION OF *Phytophthora* SPP. WITH MORTALITY OF *Pinus radiata* AND OTHER CONIFERS

II. INFLUENCE OF SOIL DRAINAGE ON DISEASE

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Summary

Deaths and defoliation of *Pinus radiata, Cupressus macrocarpa,* and other conifers in the exceptionally wet 1956 season occurred on better- as well as poorer-drained soils.

Data from 1,570 *P. radiata* and 863 *C. macrocarpa* stands led to the following conclusions:

(1) While soil drainage strongly influenced severity of symptoms, it had no major influence on extent of disease within individual stands except on very poorly drained soils.

(2) Although *P. radiata* is initially much more susceptible to the disease, it showed a very much higher recovery rate than *C. macrocarpa* on all soil types.

(3) Susceptibility of *P. radiata* increased and likewise the recovery rate of trees which had developed symptoms decreased, with increasingly poor soil drainage. Susceptibility of *C. macrocarpa,* on the other hand, was greatest at both extremes of soil drainage, while the recovery rate amongst affected stands was uniformly fairly low.

An attempt is made to explain the differences in behaviour of the two species on the basis of different rates of rootlet regeneration and fascicle or branchlet abscission.

The data from the survey could not be explained by soil physical factors alone without the presence of a pathogen. The facts emphasise that the 1956 epidemic was caused by *Phytophthora* attack during a prolonged wet season, the amount and severity of the disease being influenced by soil drainage.

Introduction

There are records of many trees of *Pinus radiata* Don dying in parts of the North Auckland Peninsula in the spring of 1924, 1936, and 1946, following prolonged and unusually heavy rainfall. Further severe mortality occurred in 1953 and 1954 in the vicinity of Auckland, and in 1956 throughout much of the North Island, and in particular the North Auckland Peninsula. Affected trees were usually 30 years or more in age. *Cupressus macrocarpa* Hartw., *Chamaecyparis lawsoniana* (L.) Parl., *P. muricata* Don, *P. pinaster* Ait., and *C. lusitanica* var. *benthami* Carr. were similarly affected in many districts.

Newhook (1959) investigated the 1953, 1954, and 1956 outbreaks near Auckland and showed that they were the result of prior attack on

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rootlets by *Phytophthora cinnamomi* Rands., *P. cactorum* (Leb. et Cohn) Schroet., and other *Phytophthora* spp., during abnormally wet autumn and spring months.

Leaves turned red in spring or early summer and severely affected trees died within one or two months of this first appearance of symptoms. Other trees did not die but suffered abnormally heavy needle-fall. The disease affected single trees or patches of up to 50 or more in extent.

Following the 1956 epidemic, a survey of the North Auckland Peninsula was undertaken in March 1957 to study occurrence of disease on different soil types and in particular to determine whether differences in soil drainage had an influence on the disease.

The survey extended from Auckland city to Te Kao near North Cape. Plantations were not included. Shelterbelts and small stands (both hereafter referred to as stands) of *P. radiata, C. macrocarpa,* and other conifers, growing within a distance of approximately one mile of the main access routes in the Peninsula were classified according to disease severity using the following scale:

o = all trees healthy.
a = slight defoliation, some or all trees.
b = severe defoliation but no deaths, some or all trees.
c = some or all trees dead.

Soils were determined from the one-inch-to-one-mile maps compiled by the first author and N. N. Taylor, in preparation for bulletins to be published on soils of North Auckland and Whangarei County. Many soil type names have already been published in connection with the General Survey of the Soils of North Island, New Zealand (N.Z. Soil Bureau 1954). New type names or new sub-types and phases of published names are marked in brackets in this paper. Out of 246 soil types described for North Auckland, 149 were involved in the *P. radiata* survey (1,570 sites) and 107 in the *C. macrocarpa* survey (863 sites). Stands of other coniferous species were less frequent and did not occur on such a wide range of soil types, e.g. 52 for *C. lawsoniana* (156 sites), 41 for *C. benthami* (95 sites), 37 for *P. pinaster* (78 sites), 19 for *P. muricata* (28 sites), 9 for all other coniferous species combined (12 sites).

Soils were divided into five main drainage classes based on the classification published in the United States Department of Agriculture Soil Survey Manual (1951):

(1) Well drained
(2) Moderately well drained
(3) Imperfectly drained
(4) Poorly drained
(5) Very poorly drained.

Where drainage characteristics varied within a particular soil type, what appeared to be the most common condition associated with pine plantings was chosen for the classification. To have defined more exactly the drainage characteristics of individual sites would have required a more detailed examination than was possible, involving

frequent checks at different times during the season. The somewhat arbitrary classification was unavoidable, but in view of the large number of sites of *P. radiata* and *C. macrocarpa* examined it is unlikely that the general pattern of response by trees to drainage and disease is significantly affected.

In the epidemic year 1956, even the better-drained soils were saturated with water for long periods from April to August. Furthermore, continual heavy rain caused abnormal surface puddling through temporary alteration of the crumb or nut structure of the soil aggregates. Where *Phytophthora* was present, conditions would have favoured fungus attack regardless of inherent drainage properties of soils. The main effect of drainage differences on the fungus would have been at the end of the winter, determining the rate at which soils returned to a state no longer favourable to *Phytophthora* attack.

The following account deals mainly with the epidemic as it affected *P. radiata* and *C. macrocarpa* since these were the only two species encountered in sufficient numbers within each soil drainage class and on a sufficiently wide range of soil types for significant conclusions to be drawn.

General Observations

Appendices 1 and 2 show that the disease was not characteristic of only a few soils but was present on most soils on which *P. radiata* and *C. macrocarpa* were growing. The same was true for other susceptible species.

Only one case of death of trees by "drowning" was seen during the survey. This was in a sand-dune plantation of *P. radiata* at Waipapakauri where the marginal trees around a small lake had apparently been killed by a prolonged rise in lake level caused by a blocked outlet.

Distribution of disease was patchy in individual stands. The patches were not always on the lowest or wettest areas but were often part-way down a slope. In fact, as will be seen from Appendices 1 and 2, several severe cases of disease occurred on hill soils.

Soil Drainage and Extent of Disease Within Stands

Extent of disease within stands was examined independently of severity of symptoms. In the survey, each affected stand was graded on a scale of 1–3 according to the proportion of trees showing symptoms. For each species the data for each of these grades for each soil drainage class (Table 1) were statistically analysed.

The soil units and grades of disease formed a 5×3 contingency table, for which independence was tested by the χ^2 test. For *P. radiata* $\chi^2 = 15.97$ with 8 degrees of freedom, P. $= 0.043$. For *C. macrocarpa* $\chi^2 = 32.54$, $P = 0.00008$. This means that soil drainage has a significant influence on extent of infection within stands.

However, if data for the very poorly drained soils are excluded from the analysis, the association is no longer significant. χ^2 for *P. radiata* $= 9.13$ (6 d.f.), $P = 0.17$ and for *C. macrocarpa* $= 3.44$, $P = 0.75$.

TABLE 1. RELATIONSHIP OF SOIL DRAINAGE TO EXTENT OF INFECTION WITHIN STANDS

Soil Drainage Class	No. Stands with the Relative Extent of Infection Indicated*					
	P. radiata			*C. macrocarpa*		
	1	2	3	1	2	3
Well drained	71	30	27	35	15	3
Moderately well drained	120	70	27	51	16	3
Imperfectly drained	110	43	33	35	11	1
Poorly drained	110	59	28	56	12	3
Very poorly drained	191	112	84	92	68	27

* 1 = less than ⅓ of trees affected
2 = between ⅓ and ⅔ of trees affected
3 = over ⅔ of trees affected

Thus any major influence of soil drainage on extent of disease within stands is confined to very poorly drained soils.

RELATIONSHIP OF DISEASE SEVERITY TO SOIL DRAINAGE CLASSES

Table 2 summarises the data for disease severity in *P. radiata* and *C. macrocarpa* on the five main soil-drainage classes. Fuller data are given in Appendices 1 and 2. In addition to giving the percentage of stands remaining outwardly healthy or showing symptoms in varying degree, Table 2 helps to illustrate the influence of soil drainage on survival of stands of diseased trees of each species, i.e. percentage of stands in which symptoms developed but no trees died. Observations since 1953 have shown that affected trees that were not dead by the end of the summer either recovered gradually or remained partially defoliated for several years, still retaining value for shelter or timber.

The data in Table 2 have been statistically analysed, percentages being compared by the χ^2 test, and the following facts of interest emerge:

(1) From the data for total diseased sites *P. radiata* is much more susceptible than *C. macrocarpa* on each soil-drainage class, the differences between each pair being highly significant ($P < 0.001$).

(2) Although initially more susceptible, *P. radiata,* once infected, has a much greater percentage survival than *C. macrocarpa* on all soil-drainage classes; the differences between each pair again being highly significant ($P < 0.001$).

(3) (a) Differences between percentage survival for infected *P. radiata* are very highly significant ($P < 0.001$) and there is a consistent gradient from well to very poorly drained soils. Therefore, the chances of survival for this species are increasingly great the better the soil drainage.

(b) *C. macrocarpa,* on the other hand appears to have a fairly uniform tendency to die rather than recover once it reaches the

TABLE 2. RELATIONSHIP BETWEEN SOIL DRAINAGE AND DISEASE SEVERITY IN *P. radiata* AND *C. macrocarpa* IN THE 1956 EPIDEMIC THROUGHOUT THE NORTH AUCKLAND PENINSULA

Host Species	Soil Drainage Class	No. Sites Examined	No. Soil Units	% Shelterbelts with the Following Relative Severity of Symptoms				Percentage Diseased Sites	*Percentage Survival
				o	a	b	c		
P. radiata	Well drained	198	27	35.4	20.2	29.8	14.6	64.6	77.3
,,	Moderately well drained	356	34	39.0	17.7	23.3	19.9	61.0	67.3
,,	Imperfectly drained	292	30	36.3	15.1	21.6	27.1	63.7	57.5
,,	Poorly drained	276	31	28.6	12.7	25.4	33.3	71.4	53.3
,,	Very poorly drained	448	27	13.6	14.3	22.8	49.3	86.4	42.9
,,	Aggregate	1570	149	29.0	15.7	24.0	31.3	71.0	55.9
C. macrocarpa	Well drained	102	19	48.0	2.0	11.8	38.2	52.0	26.4
,,	Moderately well drained	193	28	63.7	1.6	6.7	28.0	36.3	22.9
,,	Imperfectly drained	124	21	62.9	1.6	5.6	29.9	37.1	19.6
,,	Poorly drained	154	21	52.9	3.2	11.4	32.5	46.8	30.6
,,	Very poorly drained	290	18	35.5	1.4	10.3	52.8	64.5	18.2
,,	Aggregate	863	107	50.4	1.9	9.2	38.6	49.6	22.2

o = healthy stand
a = slightly affected stand
b = severely affected stand, but no deaths
c = severely affected stand, some or all trees dead

$$* \% \text{ survival} = \frac{\text{No. of diseased sites of categories a and b}}{\text{Total diseased sites}} \times 100$$

stage of showing symptoms. All possible differences within the final column are non-significant except the last ($P = 0.05 - 0.01$).

(4) (a) Although stands of *P. radiata* on all except the very poorly drained soils showed similar amounts of "total disease", there were significantly more trees dying the worse the drainage.

(b) The only significantly different results in the last three columns for *C. macrocarpa* are a greater proportion of deaths and total disease ($P < 0.001$) and a lower survival rate ($P = 0.05 - 0.01$) on very poorly drained soils and a greater proportion of total disease ($P = 0.01 - 0.001$) on well drained soils.

DISCUSSION

It was suggested earlier (Newhook 1959) that symptoms in *P. radiata* developed in spring or early summer when rootlet destruction by *Phytophthora* spp. during unusually wet autumn and winter conditions had so far exceeded rootlet regeneration that trees had insufficient rootlets to cope with the increasing demand for water. In consequence of this they wilted and died or shed needles heavily.

The differences in behaviour between *P. radiata* and *C. macrocarpa* may be explained, at least in part, by (1) differences in ability to regenerate a new rootlet system after attack by *Phytophthora* and (2) differences in rate of shedding of needle fascicles or branchlets in response to shortage of water.

The earlier paper showed that *P. radiata* has a strong capacity for rootlet regeneration even in infected soil, when soil moistures drop below field capacity. In the field this state would be most rapidly reached in better drained soils, hence the observed gradient from better to poorer drained soils with respect to total disease expression and percentage survival or recovery with *P. radiata*.

Less is known about the ability of *C. macrocarpa* to regenerate rootlets than *P. radiata* but field evidence suggests that rootlet production is slower, e.g. after planting out seedlings in North Auckland State Forests, one-year-old *P. radiata* has approximately a 50% better establishment rate than two-year-old *C. macrocarpa**. Few comparisons are available with one-year-old *C. macrocarpa* since the survival rate is so low that older seedlings are preferred for planting out. Slower production of new rootlets could help to account for the fact that once *C. macrocarpa* becomes infected to the stage of showing symptoms it tends to die rather than recover, whereas *P. radiata* has a much stronger tendency to recover on all soils. The significantly greater amount of disease in *C. macrocarpa* on well drained soils could be due to its inability to produce an adequate new root system before these soils dried out in summer.

* The following pairs of figures extracted from New Zealand Forest Service records represent percentage survivals of *C. macrocarpa* and *P. radiata* respectively. For each pair the year of planting, soil type and forest area are the same. 54–70; 50–95; 86–98; 51–78; 47–82.

Needle fascicle abscission in *P. radiata* appears to be a fairly rapid process, this perhaps helping to balance rootlet loss by reducing the transpiring area of trees. The equivalent process in *C. macrocarpa* involves shedding branchlets by abscission. If this were a slower process than fascicle abscission it would mean that *C. macrocarpa* would take longer to show defoliation symptoms than *P. radiata*. Full transpiration continuing for a longer period could mean greater and more prolonged moisture stress, with more likelihood of trees dying than with *P. radiata*.

There remains the question of whether defoliation and death could have been caused by poor drainage in the absence of *Phytophthora*, with or without aggravation by puddling by stock. It was obviously impossible to attempt to isolate *Phytophthora* from soil samples collected from the many sites involved in a survey of this size. However, the survey was complementary to the investigation of deaths of *P. radiata* and other conifers in a portion of the epidemic area, within a radius of 20 miles of Auckland. In this investigation (Newhook 1959) *Phytophthora* spp. were invariably isolated from a large percentage of soil samples from under diseased trees and were usually absent or infrequent in samples from below healthy trees. It is reasonable to assume that the same situation held for the whole of the epidemic area.

If excess soil water alone was a major cause of death in the shelterbelts, one would have expected more wholesale losses than there were in stands on the heavy soil types before any losses occurred on well drained soils. In fact, deaths occurred in 15% of stands on the latter, while losses were still restricted to patches rather than whole stands on the very poorly drained soils, 14% of the stands in this last group being completely free from any visible symptoms.

The very patchiness of the distribution of disease in individual stands suggests a pathogen rather than an unfavourable soil condition, and this is supported by the data in Table 1 which show that extent of disease within stands was independent of soil drainage, except on very poorly drained soils where the opportunity for lateral spread of *Phytophthora* in surface water would be much greater. While some of the patches could have been favourite "camping" areas for stock, those on steep slopes were not likely to be, while others occurred in double-fenced hedgerows, golf courses, urban properties, etc. Any influence by stock, if it exists, (e.g. compaction of surface soil affecting drainage, addition of extra nitrogen to soil) must be regarded as purely secondary.

There was no reason to suppose that the diseased stands seen during the survey differed in any way from the cases near Auckland which formed part of the same epidemic and which were all shown to be caused by *Phytophthora* attack when soils were abnormally wet during the preceding autumn and winter.

The nearest analogy elsewhere to the New Zealand disease is the littleleaf disease of *Pinus echinata* Mill. in south-eastern U.S.A., caused by *Phytophthora cinnamomi*. Campbell and Copeland (1954) and Copeland and McAlpine (1955) showed that although *P. cinnamomi* was comparatively uniformly abundant on soils of all drainage classes, the disease was practically absent from well drained sites.

The incidence increased as internal drainage decreased and erosion increased. Sites affected by littleleaf were mainly low in fertility. Heavy applications of inorganic nitrogen were found beneficial as a control measure.

The survey just described involved only trees on soils whose fertility had been raised by inorganic fertilisers, animal excreta, etc. Erosion on the scale influencing littleleaf disease was absent.

The New Zealand disease as dealt with in this survey differs from littleleaf disease mainly in rapidity of symptom development and in its appearance only in years of exceptionally heavy and prolonged rainfall. However, the local disease is not different from what might logically be expected of littleleaf on high fertility sites in years with much higher rainfall.

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APPENDIX 1

CLASSIFICATION OF DISEASE SYMPTOMS IN *Pinus radiata* ACCORDING TO SOIL DRAINAGE CLASSES

(1) Well Drained Soils

Soil Bur. Bull. 5 Set No.	Soil Name	Relative Severity of Symptoms				Total	Relative Extent of Spread of Disease		
		o	a	b	c		1	2	3
1	Whakapara loam & clay loam	4	1	5	1	11	4	1	2
1	Mangakahia loam & clay loam	5	3	6	4	18	11	1	1
47e	(Ohia sand)	0	0	0	1	1	1	0	0
23c	Marsden sand & peaty sandy loam	1	0	1	2	4	3	0	0
23a	Pinaki sand	4	0	3	0	7	3	0	0
23b	Whananaki sand	3	0	0	0	3	0	0	0
24	Houhora sand	6	13	11	6	36	10	9	11
24a	Red Hill sand & sandy loam	0	1	0	0	1	1	0	0
24aH	Red Hill hill soils	0	0	1	0	1	1	0	0
44H	(Kaikino sand)	0	1	0	0	1	1	0	0
44H	(Te Hapua sandy loam)	1	0	0	0	1	0	0	0
87	Awapuku clay loam	0	0	1	0	1	1	0	0
87H	Awapuku hill soils	3	0	0	0	3	0	0	0
87	Bream clay loam	3	0	0	0	3	0	0	0
95	Kiripaka bouldery silt loam	14	3	10	2	29	10	3	2
95	Ohaeawai silt loam	2	2	2	2	8	3	1	2
95a	Ohaeawai shallow & bouldery silt loam	1	2	4	2	9	5	0	3
95f	Whakapai clay loam	0	0	1	0	1	0	1	0
96	Waiotu friable clay	3	7	4	2	16	5	6	2
96H	Waiotu hills soils	4	0	1	0	5	1	0	0
96	Ruatangata friable clay	3	2	1	1	7	1	2	1
96a	Kerikeri friable clay	0	1	5	2	8	4	3	1
96	(Pungaere friable clay & gravelly clay)	0	0	0	1	1	0	1	0
95	Papakauri clay loam	2	0	0	1	3	0	1	0
95	Maunu silt loam	7	0	0	0	7	0	0	0
95e	Waimate North clay loam	4	4	3	1	12	6	1	1
96	Apotu friable clay	0	0	0	1	1	0	0	1
	Totals	70	40	59	29	198	71	30	27
	%	35.4	20.2	29.8	14.6				

(2) Moderately Well Drained Soils

24c	Red Hill sandy clay loam	19	5	5	13	42	17	4	2
23c	Red Hill complex (sands)	0	1	1	0	2	1	1	0
31H	Taumata hill soils	4	0	1	0	5	1	0	0
30b	Whirinaki clay loam	2	0	2	0	4	1	1	0
30bH	Whirinaki hill soils	2	0	0	1	3	1	0	0
27d	Omanaia sandy clay loam	6	4	3	3	16	2	5	3
31a	(Autea clay loam complex)	2	2	2	3	9	5	2	0

o = all trees healthy
a = slight defoliation, some or all trees
b = severe defoliation, some or all trees
c = some or all trees dead

1 = up to ⅓ of stand affected
2 = ⅓ to ⅔ of stand affected
3 = over ⅔ of stand affected

Continued—(2) Moderately Well Drained Soils

Soil Bur. Bull. 5 Set No.	Soil Name	o	a	b	c	Total	1	2	3
31aH	(Autea hill complex)	14	7	2	0	23	4	5	0
27aH	Waiotira hill soils, gravelly loam	2	2	2	1	7	3	0	2
31a	Waiotira clay loam	8	6	3	1	18	6	2	2
31aH	Waiotira hill soils, clay loam	13	2	3	4	22	6	2	1
31a	Waiotira brown clay loam	0	1	0	0	1	1	0	0
34d	Whareora clay loam	1	0	6	3	10	3	5	1
34	Whangaripo (clay loam)	4	0	0	3	7	3	0	0
34H	Whangaripo hill soils, clay loam	5	4	5	3	17	6	5	1
35	Marua clay loam	0	0	1	0	1	0	1	0
35H	Marua hill soils	0	1	1	0	2	2	0	0
35	Marua buff clay loam	0	0	1	0	1	1	0	0
39a	Warkworth clay	4	5	8	8	25	6	7	8
39aH	Warkworth hill soils	5	0	2	4	11	4	1	1
87b	Katui (clay loam)	16	1	0	3	20	4	0	0
88c	Kohumaru clay	1	4	3	2	10	4	2	3
88H	Waitakere hill soils	8	0	0	0	8	0	0	0
89	Waimatenui clay	4	2	1	0	7	1	2	0
89	Mangonui (clay)	2	2	6	2	12	5	2	3
89H	Mangonui hill soils	2	0	0	0	2	0	0	0
89b	Whatoro clay loam	3	1	1	0	5	1	1	0
98bH	Whatoro hill soils	2	0	0	0	2	0	0	0
88b	(Parau-Warkworth complex)	2	1	1	0	4	2	0	0
95	Kiripaka (clay loam)	0	3	3	4	10	7	3	0
95b	Whatitiri clay loam	3	0	1	0	4	1	0	0
96	Matarau friable clay	1	0	2	2	5	3	1	0
97a	Okaihau (gravelly) friable clay	3	5	5	1	14	4	7	0
97a	Okaihau gravelly friable clay, dull brown phase	0	2	7	7	16	9	7	0
109b	One Tree Point peaty sand	0	0	1	2	3	2	1	0
109b	(One Tree Point sand and peaty sand)	0	1	3	1	5	3	2	0
122b	Te Ranga buff clay loam	1	1	1	0	3	1	1	0
	Totals	139	63	83	71	356	120	70	27
	%	39.0	17.7	23.3	19.9				

(3) Imperfectly Drained Soils

44	Tangitiki sandy loam & sand	27	10	9	10	56	18	6	5
44H	Tangitiki sandy loam & sand, hill soils	5	0	1	2	8	1	1	1
7b	(Maungaturoto clays)	4	3	4	1	12	4	2	2
7b	(Maungaturoto clay, coarse structured phase)	2	0	2	2	6	3	1	0
7b	Koniti clay loam	1	0	0	0	1	0	0	0
7bH	Koniti hill soils	1	0	0	0	1	0	0	0
27H	Puhoi hill soils (pale brown clay loam)	1	0	0	1	2	1	0	0
30	Te Tio clay loam	7	1	3	1	12	4	1	0
31c	Waiotira light clay	5	2	3	3	13	6	1	1
31cH	Waiotira hill soils	2	1	1	3	7	4	1	0
30a	Omu clay loam	0	6	5	29	40	23	11	6

Continued—(3) Imperfectly Drained Soils

Soil Bur. Bull. 5 Set No.	Soil Name	o	a	b	c	Total	1	2	3
34	Whangaripo clay	3	0	1	1	5	2	0	0
34H	Whangaripo hill soils, clay	1	2	0	1	4	3	0	0
44b	Riponui clay & sandy clay	5	1	0	3	9	2	2	0
44b	Riponui sandy loam & sandy clay	3	0	1	2	6	1	2	0
38a	Wairiki clay loam & silt loam	6	2	1	4	13	4	2	1
41	Rangiora clay & silty clay loam	0	0	2	1	3	0	1	2
41H	Rangiora hill soils	1	1	1	1	4	2	0	1
46c	Otangaroa clay & sandy clay loam	3	3	0	0	6	0	2	1
46cH	Otangaroa hill soils	0	0	1	0	1	1	0	0
45	Waikare brown clay	2	0	4	2	8	5	0	1
90c	Pakotai clay	7	5	6	6	24	8	5	4
90c	Pakotai brown clay	2	0	3	0	5	2	0	1
90b	Awarua clay	2	1	3	0	6	3	1	0
90a	Aranga clay	7	1	5	2	15	5	2	1
93	Waimamaku bouldery clay	5	0	1	1	7	2	0	0
93	Onetai bouldery clay	0	0	0	1	1	1	0	0
93c	Dome Valley clay	0	2	1	0	3	1	1	1
93cH	Dome Valley hill soils	4	1	0	1	6	1	0	1
96	Tikipunga friable clay	0	2	5	1	8	3	1	4
	Totals	106	44	63	79	292	110	43	33
	%	36.3	15.1	21.6	27.1				

(4) Poorly Drained Soils

2	Whakapara mottled clay loam	0	2	4	2	8	3	4	1
7	Arapohue clay	12	9	4	10	35	17	4	2
7	(Arapohue clay, deep phase)	3	0	0	2	5	2	0	0
7aH	Motatau hill soils	1	0	0	1	2	1	0	0
27	Puhoi clay loam	2	0	0	0	2	0	0	0
27H	Puhoi hill soils, clay loam	5	0	0	0	5	0	0	0
27d	Omanaia sandy loam & sandy clay loam	8	1	3	1	13	4	1	0
33	Aponga clay & clay loam	2	8	21	37	68	34	22	10
33H	Aponga hill soils	0	0	0	1	1	1	0	0
33	Aponga Motatau complex	1	0	2	7	10	5	4	0
40	(Mt. Rex clays)	3	0	0	1	4	1	0	0
37	Rockvale clay	3	1	0	2	6	2	0	1
37	(Rockvale clay, coarse structured phase)	1	0	0	1	-	0	1	0
40	Mata clay & brown-flecked clay	1	0	1	0	2	0	1	0
38	Okaka silty clay & clay	8	2	8	0	18	2	4	4
38H	Okaka hill soils	6	1	2	0	9	2	1	0
38	(Piroa clay & silty clay)	1	1	0	0	2	1	0	0
46	Hukerenui gravelly loam	0	1	3	1	5	2	1	2
46b	Hukerenui silt loam	1	3	6	7	17	7	6	3
46bH	Hukerenui hill soils	0	0	1	1	2	2	0	0
46b	Hukerenui silt loam yellow subsoil phase	1	0	1	0	2	0	1	0
46c	Hukerenui sandy loam	5	1	1	1	8	2	1	0
88b	(Cornwallis-Waikare complex)	4	1	1	6	12	7	1	0
88bH	(Cornwallis-Waikare hill soils)	3	0	2	4	9	4	2	0

Continued—(4) Poorly Drained Soils

Sol. Bur. Bull. 5. Set No.	Soil Name	o	a	b	c	Total	1	2	3
90c	Hihi (olive clays)	1	2	0	0	3	0	1	1
72a	Otao fine sandy loam (gleyed phase)	2	2	2	0	6	3	0	1
102	Wairua clay	0	0	1	1	2	1	0	1
101f	Waipapa clay	4	0	3	1	8	2	1	1
109	(Parore peaty sandy loam)	1	0	0	2	3	2	0	0
109	Ruakaka loamy peat	0	0	3	1	4	2	2	0
107b	Otonga peaty loam	0	0	1	2	3	1	1	1
	Totals	79	35	70	92	276	110	59	28
	%	28.6	12.7	25.4	33.3				

(5) Very Poorly Drained Soils

47d	Te Kopuru sand	6	2	3	6	17	8	2	1
47dH	Te Kopuru sand (peaty phase)	1	0	0	2	3	2	0	0
7c	(Matakohe clay)	2	2	2	12	18	13	2	1
7c	Dairy Flat silty clay & silt loam	1	4	4	6	15	2	2	10
45	Waikare clay & silt loam	9	9	9	22	49	11	14	15
45	Waikare sandy clay & sandy loam	3	6	10	38	57	37	12	5
45H	Waikare hill soils, sandy clay and sandy loam	0	0	1	2	3	1	1	1
47	Wharekohe silt loam	2	3	9	7	21	8	10	1
47	Wharekohe silt loam, with pan	1	0	1	0	2	0	1	0
47a	Wharekohe sandy loam	1	2	1	0	4	1	0	2
47b	Parahaki fine sandy loam	2	0	0	0	2	0	0	0
47f	Kara (clay & silty clay)	0	0	0	2	2	2	0	0
47f	Kara silt loam	0	1	5	7	13	5	6	2
47f	Kara (sand & sandy loam)	1	1	2	1	5	0	3	1
47g	Kara strongly gleyed loams	0	1	3	2	6	3	2	1
90c	Pakotai strongly gleyed clay	1	2	0	0	3	1	0	1
90 & 45	Rangiuru-Waikare complex	0	0	0	1	1	1	0	0
73	Waitemata fine sandy loam & sandy clay loam	14	20	23	61	118	58	26	20
101	Kaipara clay & clay loam	12	7	10	17	46	15	11	8
101a	Kaipara peaty clay loam & peaty loam	2	0	2	2	6	3	1	0
101b	Kaitaia clay loam	1	2	5	23	31	12	14	4
101c	Kaitaia (peat loam & peaty clay)	0	0	2	1	3	0	1	2
101f	Kamo clay loam	0	0	2	1	3	0	1	2
101f	Waipu clay	2	2	7	5	16	7	2	5
101e	Waipu peaty clay loam & peaty loam	0	0	1	2	3	0	1	2
111c	Takahiwai clay	0	0	0	1	1	1	0	0
	Totals	61	64	102	221	448	191	112	84
	%	13.6	14.3	22.8	49.3				

APPENDIX 2

CLASSIFICATION OF DISEASE SYMPTOMS IN *Cupressus macrocarpa* ACCORDING TO SOIL DRAINAGE CLASSES

(1) Well Drained Soils

Soil Bur. Bull. 5 Set No.	Soil Name	Relative Severity of Symptoms				Total	Relative Extent of Spread of Disease		
		o	a	b	c		1	2	3
1	Whakapara loam & clay loam	5	0	3	13	21	9	5	2
1	Mangakahia loam & clay loam	10	1	2	7	20	7	3	0
23a	Pinaki sand	2	0	2	0	4	2	0	0
23b	Whananaki sand	2	0	0	3	5	0	3	0
24	Houhora sand	7	0	2	4	13	4	2	0
87	Awapuku clay loam	6	0	0	1	7	1	0	0
87H	Awapuku hill soils	1	0	0	0	1	0	0	0
95	Kiripaka bouldery silt loam	4	1	0	1	6	2	0	0
95	Ohaeawai silt loam	3	0	1	2	6	3	0	0
95a	Ohaeawai shallow & bouldery silt loam	1	0	0	0	1	0	0	0
95f	Wakapai clay loam	1	0	0	2	3	2	0	0
96	Waiotu friable clay	2	0	0	0	2	0	0	0
96	Ruatangata friable clay	1	0	0	1	2	0	0	1
96a	Kerikeri friable clay	1	0	0	0	1	0	0	0
96	(Pungaere friable clay & gravelly clay)	0	0	1	0	1	1	0	0
95	Papakauri clay loam	0	0	0	1	1	1	0	0
95	Maunu silt loam	0	0	0	2	2	2	0	0
95e	Waimate North clay loam	3	0	1	1	5	1	1	0
130	Te Kie stony loam	0	0	0	1	1	0	1	0
	Totals	49	2	12	39	102	35	15	3
	%	48.0	2.0	11.8	38.2				

(2) Moderately Well Drained Soils

24c	Red Hill sandy clay loam	35	0	3	7	45	8	2	0
23c	Red Hill complex (sands)	1	0	0	2	3	0	1	1
31H	Taumata hill soils	0	0	0	1	1	1	0	0
30b	Whirinaki clay loam	1	1	0	0	2	0	1	0
27d	Omanaia sandy clay loam	7	1	3	4	15	6	2	0
31a	(Autea clay loam complex)	0	0	0	1	1	1	0	0
31aH	(Autea hill complex)	7	0	0	3	10	3	0	0
27aH	Waiotira hill soils, gravelly loam	1	0	1	1	3	2	0	0
31a	Waiotira clay loam	1	0	0	1	2	1	0	0
31aH	Waiotira hill soils, clay loam	7	0	1	2	10	3	0	0
34d	Whareora clay loam	2	0	1	4	7	2	2	1
34	Whangaripo (clay loam)	9	0	0	4	13	2	2	0
34H	Whangaripo hill soils	6	0	0	1	7	0	1	0
35	Marua clay loam	1	0	1	1	3	2	0	0
39aH	Warkworth clay	2	0	0	3	5	2	1	0

o = all trees healthy
a = slight defoliation, some or all trees
b = severe defoliation, some or all trees
c = some or all trees dead

1 = up to ⅓ of stand affected
2 = ⅓ to ⅔ of stand affected
3 = over ⅔ of stand affected

Continued—(2) Moderately Well Drained Soils

Soil Bur. Bull. 5. Set No.	Soil Name	o	a	b	c	Total	1	2	3
39aH	Warkworth hill soils	2	0	0	0	2	0	0	0
87b	Katui (clay loam)	9	0	0	1	10	1	0	0
88c	Kohumaru clay	6	0	1	10	17	8	3	0
88H	Waitakere hill soils	5	1	1	0	7	2	0	0
89	Mangonui (clay)	1	0	0	0	1	0	0	0
89b	Whatoro clay loam	4	0	0	1	5	1	0	0
89bH	Whatoro hill soils	3	0	0	0	3	0	0	0
88b	(Parau-Warkworth complex)	1	0	0	0	1	0	0	0
88bH	(Parau-Warkworth hill soils)	5	0	0	0	5	0	0	0
95	Kiripaka (clay loam)	2	0	0	1	3	1	0	0
96	Matarau friable clay	1	0	1	2	4	1	1	1
97a	Okaihau (gravelly) friable clay	4	0	0	1	5	1	0	0
109b	One Tree Point sand & peaty sand	0	0	0	3	3	3	0	0
	Totals	123	3	13	54	193	51	16	3
	%	63.7	1.6	6.7	28.0				

(3) Imperfectly Drained Soils

44	Tangitiki sandy loam & sand	11	0	0	1	12	1	0	0
7b	(Maungaturoto clays)	14	0	0	4	18	3	0	1
7b	(Maungaturoto clay, coarse structured phase)	5	0	1	2	8	2	1	0
7c	(Maungaturoto clay & silt loam)	1	0	0	0	1	0	0	0
7b	Koniti clay loam	0	0	0	1	1	0	1	0
27	Puhoi (pale brown clay loam)	0	0	0	1	1	0	1	0
30	Te Tio clay loam	2	0	1	0	3	1	0	0
31c	Waiotira light clay	1	0	1	2	4	2	1	0
31cH	Waiotira hill soils	4	0	0	1	5	1	0	0
30a	Omu clay loam	11	0	0	0	11	0	0	0
44b	Riponui clay & sandy clay	2	0	0	2	4	2	0	0
44b	Riponui sandy loam & sandy clay	0	0	0	1	1	1	0	0
41	Rangiora clay & silty clay loam	0	0	0	1	1	1	0	0
41H	Rangiora hill soils	1	0	0	0	1	0	0	0
38a	Wairiki clay loam & silt loam	4	0	0	0	4	0	0	0
46c	Otangaroa clay & sandy clay loam	2	0	0	1	3	1	0	0
90c	Pakotai clay	9	1	3	14	27	11	6	1
90a	Aranga clay	5	1	0	0	6	1	0	0
93	Waimamaku bouldery clay	2	0	0	2	4	2	0	0
93	Dome Valley clay	0	0	1	1	2	1	1	0
96	Tikipunga friable clay	3	0	0	4	7	4	0	0
	Totals	77	2	7	38	124	34	11	2
	%	62.9	1.6	5.6	29.9				

(4) Poorly Drained Soils

Soil Bur. Bull. 5. Set No.	Soil Name	o	a	b	c	Total	1	2	3
2	Whakapara mottled clay loam	1	1	1	6	9	6	1	1
2	Mangakahia mottled clay loam	1	0	0	0	1	0	0	0
7	Arapohue clay	13	0	3	7	23	8	2	0
7	Arapohue clay (deep phase)	4	0	0	2	6	2	0	0
27d	Omanaia sandy loam & sandy clay loam	4	2	1	2	9	5	0	0
33	Aponga clay & clay loam	20	0	0	8	28	7	1	0
33	Aponga—Motatau complex	8	0	1	1	10	2	0	0
37	Rockvale clay	9	0	2	3	14	5	0	0
40	Mata clay & brown-flecked clay	0	0	0	2	2	1	1	0
38	Okaka silty clay & clay	4	0	1	3	8	3	1	0
38H	Okaka hill soils	2	0	0	2	4	2	0	0
46b	Hukerenui silt loam	4	0	1	0	5	0	1	0
46c	Hukerenui sandy loam	2	0	0	0	2	0	0	0
88b	Cromwallis—Waikare complex	2	0	0	1	3	1	0	0
88c	Kohumaru (mottled clay)	0	1	2	5	8	5	3	0
72a	Otao fine sandy loam (gleyed phase)	3	0	0	0	3	0	0	0
102	Wairua clay	0	0	0	1	1	0	1	0
101f	Waipapa clay	1	0	0	1	2	1	0	0
109	(Parore peaty sandy loam)	1	0	0	0	1	0	0	0
109	Ruakaka loamy peat	3	0	2	3	8	4	0	1
107b	Otonga peaty loam	1	1	2	3	7	5	1	0
	Totals	83	5	16	50	154	56	12	2
	%	52.9	3.2	11.4	32.5				

(5) Very Poorly Drained Soils

47d	Te Kopuru sand	6	0	1	3	10	1	3	0
7c	(Matakohe clay)	9	0	0	1	10	1	0	0
45	Waikare clay & silt loam	19	0	2	7	28	4	5	0
45	Waikare sandy clay & sandy loam	14	0	2	3	19	5	0	0
47	Wharekohe silt loam	1	0	0	1	2	0	1	0
47f	Kara silt loam	3	0	3	4	10	2	5	0
47f	Kara (sand & sandy loam)	1	0	1	0	2	1	0	0
47g	Kara strongly gleyed loam	2	0	0	0	2	0	0	0
90c	Pakotai strongly gleyed clay	2	0	1	1	4	2	0	0
90	Rangiuru clay	2	0	0	1	3	1	0	0
90 & 45	Rangiuru—Waikare complex	1	0	1	0	2	0	1	0
73	Waitemata fine sandy loam & sandy clay loam	17	2	1	14	34	13	4	0
101	Kaipara clay & clay loam	5	1	6	82	94	42	28	19
101b	Kaitaia clay loam	9	1	6	24	40	13	13	5
101c	Kaitaia (peaty loam & peaty clay)	2	0	2	4	8	2	4	0
101d	Waipu clay	7	0	5	6	18	5	4	2
110	Otonga loamy peat	1	0	0	0	1	0	0	0
111c	Takahiwai clay	2	0	0	1	3	0	0	1
	Totals	103	4	31	152	290	92	68	27
	%	35.5	1.4	10.3	52.8				

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